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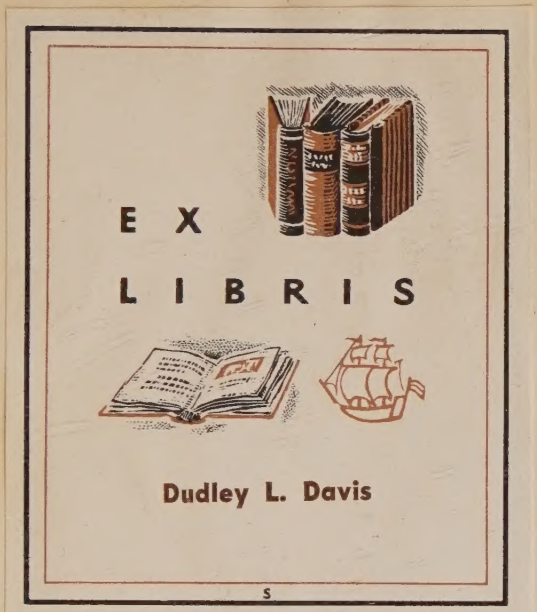

LABORATORY MANUAL
OF
TESTING MATERIALS

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BY

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THIRD EDITION
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PREFACE TO THIRD EDITION

The third edition of this manual reflects the more recent changes in standard methods of tests of materials and shifts the emphasis upon the several experiments. Some experiments of limited significance have been omitted and additional experiments supplied.

The original aims of the manual have not been changed, namely: to place the experiment in its technological setting; to offer training in technique, and knowledge of materials; and to develop a habit of critically examining the conditions and data of the experiment. In the actual practice of laboratory instruction the number of experiments performed by the student must be limited if the third result is to be reached.

The usefulness of this manual as a working tool to the practitioner has not been forgotten.

The authors gladly acknowledge the assistance of Professor R. B. Crepps of Purdue University in this revision.

W. K. H.
H. H. S.

Lafayette, Ind.,
August, 1926.

PREFACE TO FIRST EDITION

This manual is the outcome of the operation, through eighteen years, of the Laboratory for Testing Materials of Purdue University. During this time several instructors, temporarily serving the laboratory, have improved its practice. Especial mention should be made of the services of the late Professor Hancock, whose untimely death deprived the science of testing materials of a very able and patient investigator, and his colleagues of a good friend. Professor Yeoman, now of Valparaiso University, did valuable service in the organization of the work of the cement laboratory. The authors are indebted to Professor Poorman, of Purdue University, for valuable suggestions.

In its original form the manual was published by the senior author of this volume; and later, with the assistance of Professor Scofield, the manual was enlarged, and was found useful in several universities. Now the authors have availed themselves of the assistance of the present publishers to enlarge the work. The list of experiments has been increased, and a more complete treatment of machines and apparatus added.

One purpose of the manual is to relieve the instructor from the necessity of explaining the details of mechanical procedure, and so to free his time for matters of greater educational importance. It is also hoped by the authors that the practitioner will find the volume of convenient use.

LAFAYETTE, IND.,
August, 1913.

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LABORATORY MANUAL OF TESTING MATERIALS

CHAPTER I

GENERAL

1. The student should obtain a knowledge of materials by handling them and watching their behavior under stress. From the appearance before and after test, he is led to recognize the nature of normal and defective samples. This knowledge will give character to the work of engineering design, and will be of service in work of inspection.

2. A knowledge of the technique of testing materials should be gained, by which he may know afterwards if proper methods are being used in cases that come under his inspection, and by which he may judge the significance of results of the tests of material submitted to him.

3. A training should result in precise methods of observation.

4. The class-room instruction in Applied Mechanics which should precede or accompany this course, is reinforced with concrete knowledge of things and properties, which are otherwise only words defined in text-books. The application of theoretical analysis to the tests performed in the laboratory becomes of individual interest and is fixed in the mind. Discrepancies between theoretical deductions and results of tests of actual material as

supplied to the market also become evident. Many of the fundamental facts relating to metals, such as the relative stiffness of hard and soft steel, the elevation of the yield point, and the lowering of the elastic limit through overstrain can also be brought to the student's notice by a few well-selected experiments.

5. The report which accompanies the investigational features of the work, affords practice in setting forth results in a clear business-like way and should aid the student in forming at least the fundamentals of a style which will be later useful to him.

6. The student should refer to standard text-books and specifications to compare the results obtained with recorded data.

A partial list of specifications suitable for use is as follows:

Specifications in Year Book of American Society for Testing Materials.
Specifications in Year Book of State Highway Commissions.
Materials of Construction by A. P. Mills.
Materials of Construction by J. B. Johnson.
Materials of Construction by Thurston.
Materials of Construction by Upton.
Mechanics of Materials by M. Merriman.
Applied Mechanics by A. P. Poorman.
Concrete Plain and Reinforced by Taylor and Thompson.
Reinforced Concrete by G. A. Hool.
Concrete Engineers' Handbook by Hool and Johnson.
Mechanical Properties of Woods grown in the United States Bulletin No. 566 U. S. Dept. of Agriculture.

7. Thesis work in testing materials presents a ready and attractive medium by which students can receive some training in proper methods of planning and executing experimental investigations. The work may be individual, or performed by groups of students, and

the expense of material is small. If the professor is interested in some one field of investigation and systematically plans for a term of years, the theses in time are of use in extending knowledge.

The method of administering thesis work in general involves the following steps: A list of problems, to which, on account of limitations of equipment and the desire to concentrate, the work of the laboratory should be confined, is prepared early in the year. Theses subjects are generally chosen from this list by students. When a subject is chosen by a student, a thesis outline is prepared by the professor in consultation with the student, in which the problem is clearly stated; the authorities, if any, cited; a list of literature, or directions to main source of information given; and the main plan of attack fairly definitely indicated. Details of apparatus, etc., are generally left to the student. A student may present a subject of his own choice. The written thesis covers a clear and logical account of the purpose of the thesis; the material tested; the methods and machines, with a discussion or error; the actual results; the analysis and presentation of the results; and the conclusions therefrom.

CHAPTER II

GENERAL INSTRUCTIONS

Preliminary Notes.—In all tests, first carefully examine the material. Measure, and note characteristics and defects, if any. If this is not done before the specimen is broken, the test is useless. Note the serial number if any.

The character of the log sheet will be considered in grading the report.

The student should understand the manipulation and reading of all instruments used in each test.

Enough readings should be taken to accurately determine the stress-strain curve. Calculate from table of average strengths of materials, see appendix, the increment of loading required to give at least 18 readings. When quantities being measured are changing rapidly, intervals must be shortened.

Specimens upon which further observations are to be made should be carefully marked and placed in assigned case.

If the reports are to be written in the laboratory during the assigned period, all notes and data, together with unfinished reports, must be left in the filing case.

Operation of Machines During Test.— Preliminary to every test, each student should become familiar with the operation and mechanism of the testing machine to be used.

Balance poise at zero with test piece in the machine but free from the pulling head in every way.

All readings upon test piece for a certain load should be taken when the beam is balanced at the load and at no other time. The finger may be used to lift the beam slightly and so give warning which will prevent the loads being exceeded.

The speed of applying the load should be such that the beam may be kept balanced, otherwise the readings will be of doubtful accuracy.

Often after the elastic limit has been reached a faster speed may be used and much time saved. Any consistent speed is allowable if the load readings are accurate, except in experiments for which the machine speed to be used is stated in the instructions. **Students should be sure that machines are properly thrown out of gear when the test is finished.**

CAUTION.—Testing machines have upon different occasions been left by the operators with countershaft running and the friction clutches thrown in, so that the machines continued running. The result has usually been that some part of the machine was broken. The operator will take especial care that this does not occur with machines for which he is responsible. He will be charged with all the repairs made necessary by careless handling.

Note Keeping.—The standard data sheets will in most cases be used for note keeping. In the case of most of the experiments the original log of the test will be required as a part of the report. Carbon copies of the original log made in the laboratory will be acceptable in case the work is of such a character that only one of two men can record the data obtained. Neat and orderly notes and test logs will be insisted upon.

Reports.—Reports will be written in ink or typewritten on one side only of the standard $8'' \times 10\frac{1}{2}''$

paper and placed in the regular manila cover. On the outside of the cover will appear the required information in lettering.

Clearness and order of statement, legibility of writing, lettering and neatness will receive due attention in marking the report.

In plotting stress-strain curves, select such a scale as can easily be read by inspection, in decimals. State plainly the scale of coordinates. Use the bow pen to circle the points plotted, and draw curves with instruments. Use India ink for curves and lettering on the curve sheets. Avoid lines from point to point.

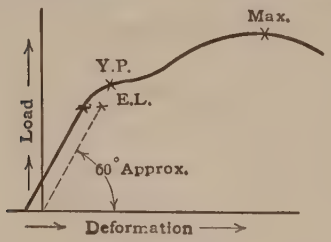

FIG. 1.

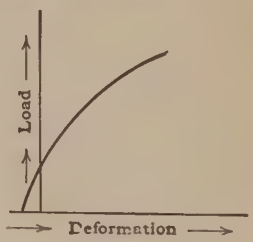

FIG. 2.

FIGS. 1 AND 2.—Stress diagrams.

The general form of load-deformation curve should be noted. Figure (1) represents a characteristic curve of ductile materials where the curve is drawn a straight line to the elastic limit averaging the plotted points. Figure (2) represents the curve for brittle materials. Select scales of coordinates so that the slope of the portion below the elastic limit is about 60°. As in Fig. 1 when curve does not start at origin draw a parallel line through origin to the elastic limit.

The title of the curve sheet should be placed in the lower right-hand corner and should contain such information that a busy man unacquainted with the

experiment, glancing at the curve sheet, would grasp the main facts without aid of the written report.

The student will note carefully any characteristics of the curve that are peculiar and state reasons for their appearance and how they can be avoided if they seem to be errors.

INSTRUCTIONS FOR WRITING REPORTS

The clerical part of the report should be suitable for submission to a practising engineer, who would naturally judge of the qualifications of the writer by the neatness and system of the report.

The sequence and the form in which the results are presented must be such as to enable a busy man to ascertain in a few moments just what was done and what was determined. *A careful study should be given to economy of language in writing the report.*

Suggested Form of Reports

Title.—The title should indicate briefly what is covered by the report.

Purpose.—Under this heading the purpose, or purposes, of the tests should be concisely stated.

Materials Tested.—It is important that the materials tested should be concisely and definitely described. It is ordinarily sufficient to define the material as to its kind, size, shape and condition, although any other *essential* descriptive facts should be stated. Dimensioned sketches are frequently necessary to properly describe the test specimens. Reference should here be made to any sketches, descriptive of the material, appearing in an appendix or elsewhere in the report. Give page.

Apparatus.—Important special apparatus, only, should be listed and concisely and accurately described.

Diagrammatic sketches are frequently necessary to properly describe apparatus as used. Reference should be here made to diagrams or sketches descriptive of apparatus appearing elsewhere in the report.

Method of Test.—Only the essential details of the testing procedure will be concisely and accurately given. It is not usually necessary to include in this division the unessential details of manipulation and measurement which are more or less common to all experimental work of this nature. It is important, however, to use good judgment in the selection and statement of such details of procedure, as to afford a proper and clear interpretation and comprehension of the results obtained.

Results of Tests.—The summarized results of the tests should be given under this heading. The results are usually most conveniently and clearly shown in summary tables. Care should be taken that summaries should be accurate and concordant with the facts shown elsewhere in the report. Averages should be accompanied by a statement as to how many and what data are included.

Discussion and Conclusions.—Explain the significance of the curves used to present graphically the results of the tests. (It should be here emphasized that curve sheets should be clear and as far as possible self-explanatory.) Where there are standard specifications for the material and test, a comparison with these standards should be shown. The standards should be quoted and authority and reference given. The specifications of the American Society for Testing Materials and other national societies should be consulted.

Comparisons with published data by other authorities, along similar lines, are generally necessary for the proper

interpretation of the test results. *Give references* Attention should be called to the factors affecting the accuracy, uniformity and validity of the results as shown.

The significance and importance of the test and results should be discussed.

The conclusions drawn should take all of the above considerations into account, particularly those which are affected by the limitation of the testing apparatus used, the personal factor involved in the methods and special or unusual characteristics, or defects, in the test specimens visible either before or after the completion of the tests.

CHAPTER III

DEFINITIONS

As supplementing the text-books in mechanics the following definitions are recorded for reference:

For formulas and symbols see Appendix.

Stress is the internal, equal and opposite, action and reaction between two portions of a deformed body. Stress is a distributed force, and is expressed in force units. As in case of deformations, stresses are: (1) normal, S, either tensile (+) accompanying a lengthening of a bar, or compressive (−) accompanying a shortening of a bar; and (2) tangential or shearing, S_s, when acting parallel to a section and accompanying a change of angle of the faces.

Uniformly distributed normal stress accompanies a load that acts along a geometric axis of a bar.

Unit stress (pounds per square inch) is the amount of stress per unit of area of surface.

The word *strain* is often used to express both deformation and stress. When used below it means deformation.

Stress-strain diagrams (Fig. 3) are drawn from data obtained in tests of materials in which gradually increasing loads are applied from zero until rupture occurs. Unit deformations are shown as abscissae, and unit stresses as ordinates, tension (+) and compression (−). Such diagrams display the most important mechanical properties of materials. Figure 3 shows several such diagrams. The tension deformations at small loads are shown in magnified scale to the right and the

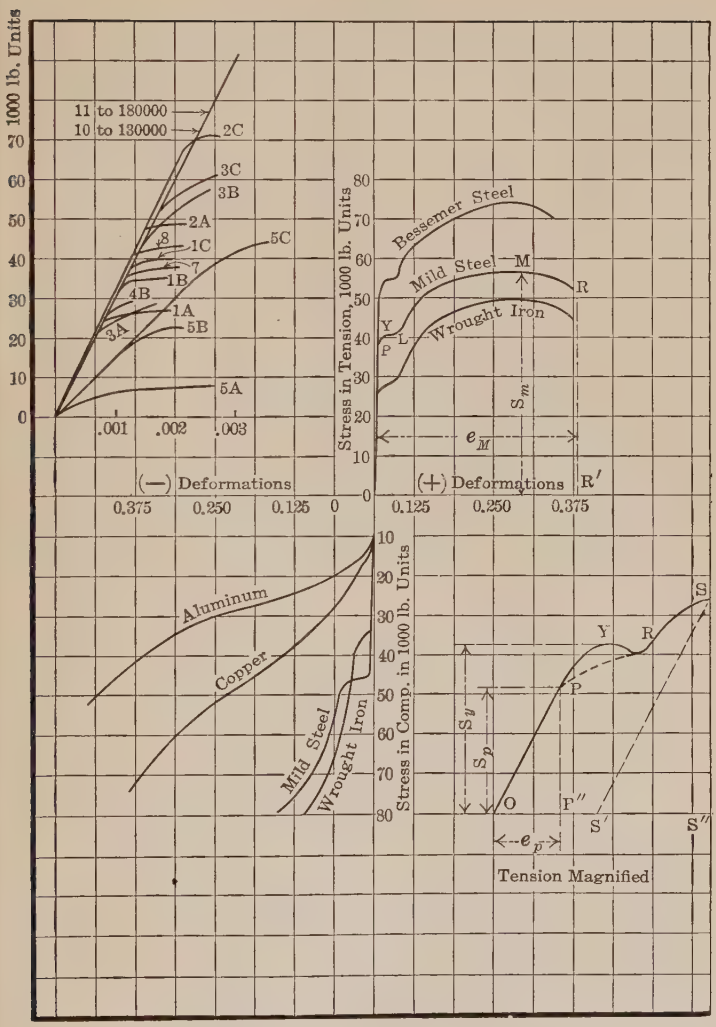
1000 lb. Units
11 to 180000
10 to 130000
2C
3C
3B
2A
8
1C
7
1B
4B
1A
3A
5B
5C
5A
.001
.002
.003
(−) Deformations
0.375
0.250
0.125
0
Stress in Tension, 1000 lb. Units
Bessemer Steel
Mild Steel
M
R
Y
L
P
Wrought Iron
S_m
e_M
(+) Deformations
R′
0.125
0.250
0.375
Aluminum
Copper
Mild Steel
Wrought Iron
Stress in Comp. in 1000 lb. Units
S
Y
R
P
S_y
S_p
O
P″
S′
S″
e_p
Tension Magnified

FIG. 3.

relative values of S_p for various materials to the left. The stresses are not actual but nominal, because the load is divided by the original, and not by the actual, deformed area.

ELASTICITY

Elasticity is the tendency of deformed bodies to resume their former shape.

Elastic Limit is the limit of stress within which the deformation completely disappears after the removal of the stress. As measured in tests, and used in design this term refers to the *proportional elastic limit*, S_p, which is the unit stress within which stresses and deformations are directly proportional. At the *Commercial Elastic Limit* or *Yield Point*, S_y, some materials experience a sudden and large increase of deformation without increase of stress. S_p is from 0.75 S_y (hot-rolled steel) to 0.90 S_y (annealed steel). Location of S_y depends upon speed of stress.

KEY TO CURVES IN UPPER LEFT HAND CORNER FIG. 3.

Curve No. 1 A—Soft O. H. Steel, as rolled.
Curve No. 1 B—Soft O. H. Steel, oil tempered and annealed.
Curve No. 1 C—Soft O. H. Steel, oil tempered.
Curve No. 2 A—Axle Steel, as rolled.
Curve No. 2 C—Axle Steel, oil tempered
Curve No. 3 A—O. H. Steel, forged disc.
Curve No. 3 B—O. H. Steel, forged disc, oil tempered and annealed.
Curve No. 3 C—O. H. Steel, forged disc, oil tempered.
Curve No. 4 B—Heavy Steel Casting, annealed
Curve No. 5 A—Cast Copper, annealed.
Curve No. 5 B—Cast Copper.
Curve No. 5 C—Hard Rolled Copper.
Curve No. 7 —Wrought Iron.
Curve No. 8 —Steel Casting, rim of small gear.
Curve No. 10 —Chrome Tungsten.
Curve No. 11 —Vanadium Steel.

Hooke's Law states that, within the elastic limit, the deformation produced is proportional to the stress.

NOTE.—Unless modified, the deduced formulas of mechanics apply only within the elastic limit. Beyond this the formulas are modified by experimental coefficients, as for instance, modulus of rupture.

Modulus of Elasticity (pounds per square inch) is the ratio of the increment of unit stress to increment of unit deformation within the elastic limit.

The Modulus of Elasticity in Tension, or Young's Modulus, E, is graphically measured by the slope of *OP* (Fig. 3); the compression modulus by the slope of *OP'*. The inverse values of E for several materials express the relative unit deformations of these materials under the same unit stress. *E is a measure of stiffness.*

Modulus of Elasticity in Shear, F, is the shearing unit stress divided by the angle of distortion expressed in radians. Theoretically, $F = nE/2(n + 1)$; and when $n = 3$, $F = \frac{3}{8}E$. (See Poisson's ratio.)

Bulk Modulus of Elasticity, B, is the ratio of unit stress, applied to all side faces of a cube, to the unit change of volume. Theoretically, $B = \frac{1}{3}\ En/(n - 2)$; and when $n = 3$, $B = E$.

Lateral Deformation, e', accompanies longitudinal deformation, *e*. *Poisson's Ratio, m,* is the ratio of e' to e. The inverse value of m is denoted by n, that is, $n = 1/m$.

Values of m given by Unwin are: Flint Glass, 0.244; Brass, 0.333; Copper, 0.333; Cast Iron, 0.270; Wrought Iron, 0.278; Steel, 0.303; Concrete, according to Talbot, 0.10.

Change of volume, under longitudinal deformation. l, d, b, = length, width and thickness; m = Poisson's ratio; s = unit deformation. Deformed volume

$= (1 + s)l(1 - ms)b(1 - ms)d = (1 + s - 2ms)ibd.$

Fractional change of volume = $(1 - 2m)s$. When m is less than $\frac{1}{2}$ the volume is increased in tension and decreased in compression. For steel, $(m = \frac{1}{3})$, change of volume is about $\frac{1}{3000}$ part at the elastic limit.

A bar under stress does not at once assume the length due to its modulus of elasticity E. Deformation proceeds for days and weeks. These phenomena of *residual elasticity or elastic afterworking* do not seem to be of practical importance.

RESILIENCE

Resilience, K, (inch-pound) is the potential *elastic energy* stored up in a deformed body. For instance, a falling weight compresses a spring; the stored energy, or resilience, of the material is a source of work and will produce return motion in the weight.

The amount of resilience is equal to the work required to deform the volume of material from zero stress to stress S.

For longitudinal deformation (Fig. 3), P = load, e = deformation, S = unit stress, E = modulus of elasticity, l = length, A = area cross section, V = volume. Resilience = work of deformation = average force $\times$ deformation = $\frac{1}{2}Pe = \frac{1}{2}AS\ Sl/E$, or

$$K = V\tfrac{1}{2}S^2/E.$$

The resilience for any other kind of stress such as shearing, bending, torsion, is the volume times a constant C times one-half the square of the stress divided by the appropriate modulus of elasticity.

Resilience of solids of *varying section* cannot be expressed per unit of volume.

Modulus of resilience, K_p (inch-pounds per cubic inch), or *unit resilience*, is the elastic energy stored up in a unit volume at the elastic limit. For longitudinal

deformation K_p is graphically measured by the area OPP''. (Fig. 3.) $K_p = \frac{1}{2} S^2/E$.

RESILIENCE PER UNIT OF VOLUME—K

S = longitudinal stress, Sv = shearing stress, E = tension modulus of elasticity, F = shearing modulus of elasticity

		SPRINGS.	
1. Tension or compression	$\frac{1}{2}S^2/E$	Carriage	$\frac{1}{6}S^2/E$
2. Shear	$\frac{1}{2}Sv^2/F$	*Flat spiral* rect section.	$\frac{1}{4}S^2/E$
BEAMS, free ends (Nos. 3–8)			
3 Rectangular section, bent in arc of circle. No shear	$\frac{1}{6}S^2/E$		
4. Rectangular section, bent in arc of circle. Circular section.	$\frac{1}{8}S^2/E$	*Helical* – axial load, circular wire.	$\frac{1}{4}Sv^2$
5. *Concentrated center load.* Rectangular cross section.	$\frac{1}{18}S^2/E$	*Helical* – axial twist.	$\frac{1}{6}Sv^2/F$
6. *Concentrated center load.* Circular cross section	$\frac{1}{12}S^2/E$		
7. *Uniform load.* Rectangular cross section.			
8. I-beam section	$\frac{9}{32}S^2/E$		
TORSION. (9–10)			
9. Solid, circular	$\frac{1}{4}Sv^2/F$		
10. Hollow, radii, R_2 and R_1	$\{(R_1^2 + R_2^2)/R_1^2\}\frac{1}{4}Sv^2/F$		

The unit resilience stored up at a stress *beyond* the *elastic limit* is measured by the area of the triangle $S''SS'$ (Fig. 3).

Unit rupture work, K_r, sometimes called *Ultimate Resilience*, is measured by the area of the stress-deformation diagram to rupture, $O\ P\ Y\ M\ R\ R'$, (Fig. 3).

$$K_r = \frac{1}{3}\ e_u\ (S_y + 2S_m) \quad . \quad . \quad . \quad . \text{ approx.} \qquad (6)$$

Here e_u = the unit elongation at rupture.

For structural steel, for instance, $K_r = \frac{1}{3}\ \frac{27}{100}\ (35{,}000 + 2 \times 60{,}000) = 13{,}950$ (inch-pounds per cubic inch).

CHAPTER IV

MATERIAL STRESSED BEYOND THE ELASTIC LIMIT

Beyond elastic limit in tension S_p, ductile materials like steel enter a semi-plastic stage. The material stretches from Y to L (Fig. 3) without increase of stress, and the scale beam of the testing machine "*drops*," and the hard mill-scale falls from bar. Yielding proceeds from either shoulder of bar to center. Steel shows both S_p and S_y; cast iron, neither S_y nor S_p; wood and hardened steel, S_p, but no S_y.

The shape of the diagram from S_p to S_y depends upon *speed of stress*. Ewing found full line for fast, and dotted line, for very slow, speed (Fig. 3).

After L semi-plastic and semi-elastic deformations proceed. One or several contractions of cross section occur depending upon homogeneity of metal. The *maximum load* is reached at M (Fig. 3) when the metal at one of these contractions begins to flow. The contraction or "neck" proceeds until bar ruptures at R. The character of the metal changes under this excessive deformation, and, therefore, the actual stress on the ruptured section is not of practical importance, and is not observed.

Ultimate strength S_m = maximum load/original area. The elongation and contraction after rupture are observed.

The load may be released at intervals to observe the set, OS'' (Fig. 3).

Fracture under tension indicates quality of material, but is influenced by speed and method of producing fracture, and by shape of test piece. A metal that is tough and fibrous may appear crystalline if broken quickly at a nicked section. Contraction is greatest in tough and ductile, and least in brittle, materials. The *shape* of fracture is usually a center flat surface of failure in tension surrounded by a rim on which the metal shears. The extent of the rim is more pronounced when the ratio of shearing to tensile strength is less; is more developed in soft steels; becomes a complete cone in very soft materials; and vanishes in cast iron. The color, grain and shear of the fracture are insignificant. *Forms of fracture* in tension are shown in Fig. 4.

Terms describing fracture are: silky, dull, granular, crystalline, fibrous.

Failure under compression depends on material, slenderness of specimen, and restraint at ends or sides. *Short blocks* of *brittle materials* in compression like cast iron, stone, cement, when unconfined at the sides, fail by sliding along inclined planes. The angle of these planes is a function of the shearing stress and of the coefficient of friction of the material. The theoretical angle of fracture, with the cross section is $\pi/4 + \phi/2$ where ϕ is angle of repose of material. Internal cones, with their bases at the pressure heads of the testing machines, and pyramids, form in cylindrical and rectangular specimens respectively.

Ductile or soft material, like copper and soft steel, cannot be ruptured in compression. They bulge, increase in diameter under increasing stress, and finally become plastic at the *stress of fluiditiy*. That is, the deformation proceeds under a constant actual stress, per unit of deformed area, and is permanent.

The product of deformation and load (or normal stress) is then constant, and is expressed by a rectangular hyperbola. The outer portions of the stress strain diagram for lead and copper in Fig. 3 are approximately hyperbolic.

Unwin quotes the following values for pressure of fluidity in pounds per square inch. Mild steel, 112,000; Copper 54,000; Lead 1700. Experiment by Hatt gives for wrought iron, 76,000.

The strength of materials of medium ductility, like steel and wrought iron, in compression is generally to be taken at the yield point of the material.

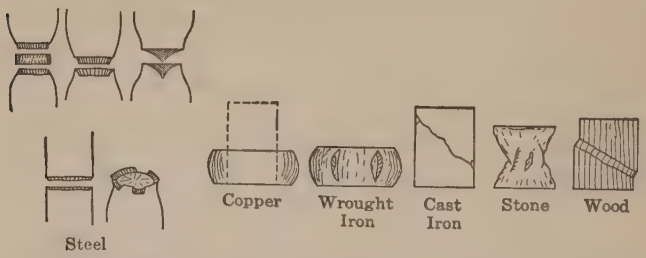

FIG. 4.—Characteristic fractures of materials in tension and compression.

Strength under compression depends on ratio of length to diameter of specimen.

The compressive strength of stone and concrete is about 10 times the tensile strength.

Fracture forms for several materials in compression are shown in Fig. 4.

Failure under pure shear is difficult to produce. The common form of test introduces bending stresses.

Ratio of shearing strength to compressive strength is not well determined. For concrete and brittle materials this ratio is reported to vary from 0.32 to 1.25.

The ultimate shearing strength of steel and iron is nearly three quarters of its tensile strength.

Hancock's Tests (Proc. Am. Soc. Test. Mat., 1908, p. 376) show that the shearing elastic limit of steel and iron, determined in torsion, is 0.50 to 0.57 the proportional elastic limit in tension.

Failure of steel at or above the elastic limit is accompanied by appearance of *Hartmann's lines* on polished surfaces. These lines make an angle, with the axis of a tension bar, of 63° for soft steel, and 58° for annealed steel. They indicate a slippage along the cleavage planes of the crystals of the metal. Steel consists of an aggregation of crystalline grains separated by films or membranes of material of different compositions. Under this view failure in tension or compression is essentially a failure under shearing stress modified by internal friction.

CHAPTER V

TESTING AND TESTING MACHINES

Technical qualities of materials may be grouped as:

Technological, having to do with manufacturing requirements, such as malleability, fusibility, forgeability, bending to shape.

Physical, such as specific gravity, plasticity, homogeneity, durability, structural characteristics, including fibrous, crystalline.

Mechanical properties examined in tests. These are listed in table below, together with criteria commonly used.

Quality	Service	Criteria	Example
Strength.....	To carry dead load.	Ultimate strength.	Piano wire.
Elasticity...	To undergo deformation and return to shape	Amount of elastic deformation.	Rubber.
Resilience...	To absorb energy without permanent deformation	Modulus of resilience.	Second growth hickory.
Stiffness....	To carry load without deformation.	Modulus of elasticity.	Steel.
Hardness...	To (*a*) withstand wear; (*b*) to resist penetration.	Scratch test; abrasion test. Brinnel test.	Manganese steel.
Toughness	Various conceptions; to endure large permanent deformations; to withstand large energy without rupture.	Various.	Rivet steel; hickory wood
Endurance	To withstand repetition of stress with small shocks.	Endurance test.	Vanadium steel.
Plasticity...	The absence of elasticity.	Deform without return or rupture.	Lead.

Testing Machines

Testing Machines must be accurate and sensitive.

Accuracy depends on correct lever proportioning, condition of knife edges, and stiffness of levers. (See Experiment A-2.)

For sensitiveness knife edges should be of small radius, and straight, and stiff. Knife edge machines are usually more sensitive than necessary. Machines should be examined for clearance of levers from frame of machine. (See Experiment A-2.)

Specimens under test should not be subject to shocks or vibrations arising from the power elements of the machine, as for instance inertia of levers when specimen takes sudden elongation, or by the action of the pump in setting a body of liquid in motion.

Machines vary in capacity from wire tester of 600 lb. capacity to U. S. Govt. machines of 10,000,000 lb. capacity in compression. For ordinary use in a commercial laboratory, a machine of 200,000 lb. capacity is most suitable. For instruction of students a machine of 30,000 lb. capacity is most convenient. The present limit of screw-power scale beam machines for tension and compression is 1,000,000 lb.

The following table of large capacity testing machines is taken from an article by E. L. Lasier in the proceedings of the American Society of Testing Materials, 1913.

Static testing machines must provide proper means for (*a*) holding specimen, (*b*) applying load, and (*c*) weighing the load. Mechanical problems of gearing, absorbing shock, and oiling must be solved.

(*a*) Holding the Specimen

Tension and Compression.—It is important in testing a specimen in tension and compression, that the load

Large Capacity Testing Machines in the United States and England

Machine	Type	Capacity, lb.		Power	Weighing device	Maximum length of specimen, ft.		Date of completion
		Tension	Compression			Tension	Compression	
Bureau of Standards, Washington, D. C.	Vertical	None	10,000,000	Hydraulic	Balance beam	None	25	1912
American Bridge Company, Ambridge, Pa.	Horizontal	4,000,000	None	Hydraulic	Mercury gage	42	None	1905
Phœnix Iron Company, Phœnixville, Pa.	Horizontal	2,800,000	2,800,000	Hydraulic	Mercury gage	50	55	1886
Bureau of Standards, Washington, D. C.	Horizontal	1,150,000	2,300,000	Hydraulic	Emery scale	33	33	1913
United States Steel Company, McKeesport, Pa.	Horizontal	1,200,000	800,000	Hydraulic	Mercury gage	40	32	
Rensselaer Polytechnic Institute, Troy, N. Y.	Vertical	None	1,200,000	Hydraulic	Balance beam	None	3	1909
Bureau of Standards, Washington, D. C.	Vertical	None	1,000,000	Hydraulic	Pressure gage	None	9	1909
Department of Public Works, Philadelphia, Pa.	Vertical	None	1,000,000	Hydraulic	Pressure gage	None	3	
Pennsylvania Railroad, Altoona, Pa.	Vertical	1,000,000	1,000,000	Screw	Balance beam	4	4	
American Steel Foundries, Alliance, Ohio	Vertical	1,000,000	1,000,000	Screw	Balance beam	3	3	
Watertown Arsenal, Watertown, Mass.	Horizontal	800,000	800,000	Hydraulic	Emery scale	20	26	1879
Lehigh University, South Bethlehem, Pa.	Vertical	800,000	800,000	Screw	Balance beam	24	24	1910
Joshua Buckton & Company, England	Horizontal	784,000	784,000	Hydraulic	Balance beam	20	5	
Joshua Buckton & Company, England	Horizontal	672,000	672,000	Hydraulic	Balance beam	80	80	1909
Birmingham University, England	Horizontal	672,000	672,000	Hydraulic	Balance beam	33	30	1909
Bureau of Standards, Pittsburgh, Pa.	Vertical	600,000	600,000	Screw	Balance beam	24	30	
Rensselaer Polytechnic Institute, Troy, N. Y.	Vertical	600,000	600,000	Screw	Balance beam	22	24	
University of Illinois, Urbana, Ill.	Vertical	600,000	600,000	Screw	Balance beam	22	25	1905
University of Pennsylvania, Philadelphia, Pa.	Vertical	600,000	600,000	Screw	Balance beam	22	14	1908
University of Wisconsin, Madison, Wis.	Vertical	470,000	600,000	Hydraulic	Pressure gage	10	12	1907
Baltimore & Ohio Railroad		600,000	600,000	Screw	Balance beam	22	24	
American Steel & Wire Company, Pittsburgh, Pa.	Vertical							
	Vertical	600,000	600,000	Screw	Balance beam	22	24	
Pressed Steel Car Company, Pittsburgh, Pa.	Vertical	600,000	600,000	Screw	Balance beam	22	24	

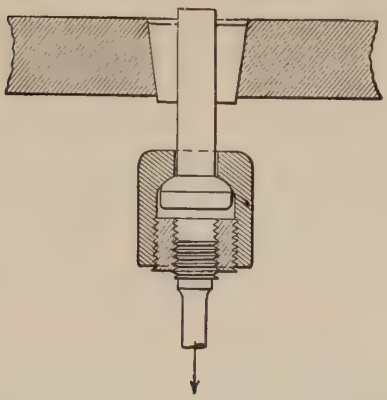

FIG. 5.—Universal joint for holding screw end test piece in tension.

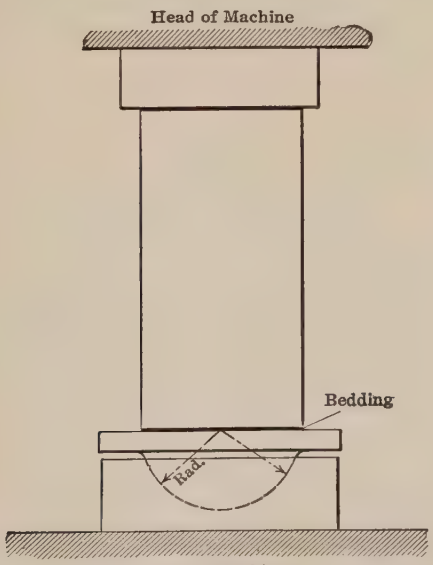

FIG. 6.—Spherical bearing plate and method of supporting test piece in compression.

is applied as nearly as possible in the axis of the test piece. This implies that the specimen should be accurately centered in the testing machine. The common method of holding the test bar is by serrated wedges with flat face, which is suitable for ductile materials. For brittle materials, or short specimens, it is customary to use a spherical, or universal, joint between the specimen and the testing machine. These if correctly designed do away with bending and buckling in the specimen.

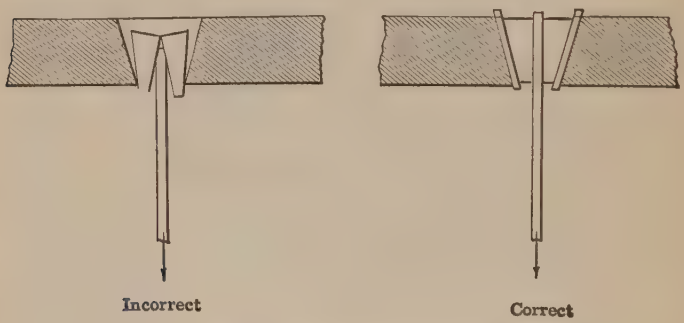

FIG. 7.—Method of gripping test specimen in tension.

Fig. 5 and 6 illustrate the adaptation of the universal joint to tension and compression tests.[1] Fig. 5 shows a convenient apparatus for gripping the standard short screw-end test piece and Fig. 6 shows the common method of supporting concrete or other like material in compression. A bedding of Plaster of Paris or blotting paper is used between the specimen and the surfaces of the machine, to give an even application of the load.

Fig. 7 indicates a correct and an incorrect way to grip a specimen in tension. The test piece should extend

[1] NOTE: For compression tests of concrete the spherical bearing plate should be placed on top of the specimen.

through the grips and these should have their full bearing over their entire length in the heads of the testing machine.

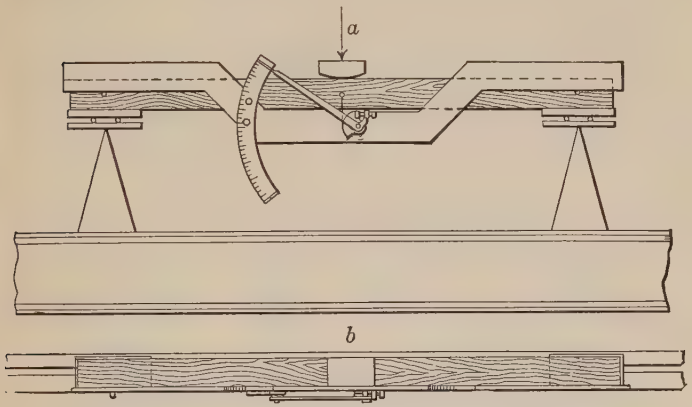

FIG. 8.—An apparatus for testing small beams in flexure.

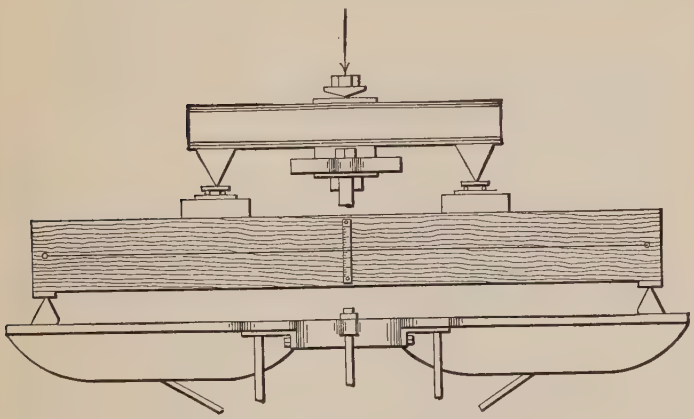

FIG. 9.—A method of testing large beams in flexure.

Flexure tests require freedom of specimen to bend and rollers should be placed between supports and

specimen. In case an auxiliary straining beam is used, rollers are especially necessary to prevent compounding of straining beam and specimen through the horizontal shear at the loading points.

Figs. 8 and 9 show apparatus as used by the Forest Service in the tests of timber. In Fig. 8, the supporting beam is conveniently laid across the weighing table of a small capacity testing machine. The rollers and plates

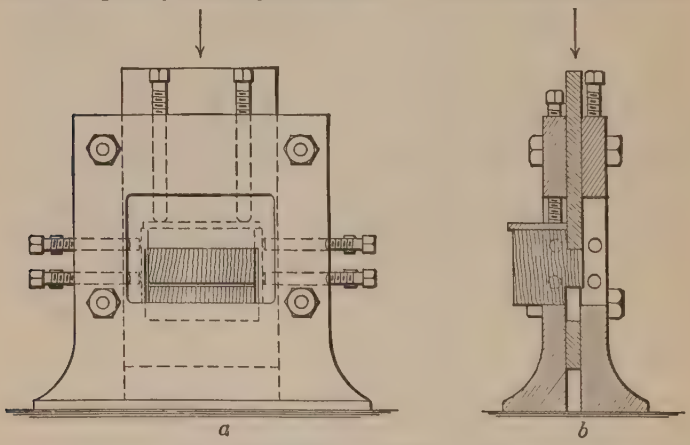

FIG. 10.—A shearing apparatus for wood.

between supports and specimen prevent local failure and binding at the supports.

In testing large beams, Fig. 9, it is customary to apply the loads at the third points by means of an auxiliary beam with rollers and plates. The knife edge supports are, in this case, so constructed that they rock freely as the beam bends downward.

Shear Tests.—Shearing shackles and tools should produce pure shear without bending. Fig. 10 shows a simple and reliable shearing tool for tests of timber. It is supported directly on the weighing table of the

testing machine and the plunger comes in direct contact with the under side of the movable head.

(b) Method of Applying the Load

Loads are applied mainly by screw power (Olsen or Riehlé); or (2) hydraulic power (Emery or Amsler).

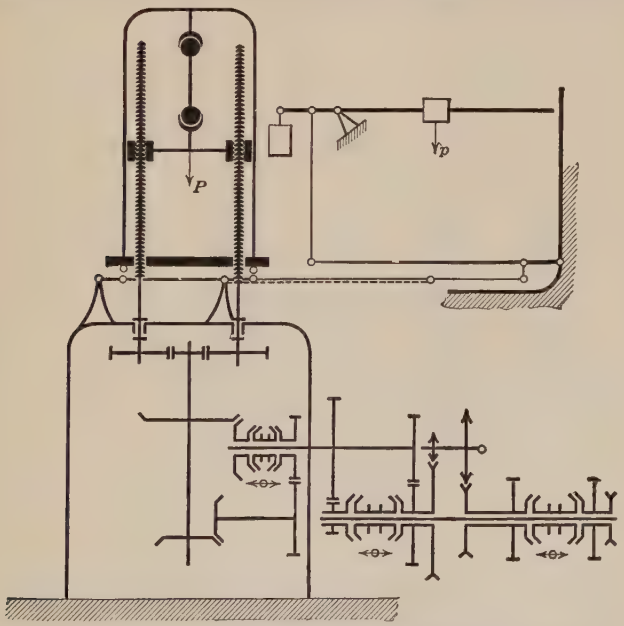

Fig. 11.—Diagrammatic view of a Riehlé testing machine. (Modified from Marten's Handbook of Testing Materials.)

Screw Machines.—American machines are commonly of screw power. Old screw machines should be examined to see if the wear of the threads produces an oscillatory motion of the testing heads.

Fig. 11 represents by diagram a Riehlé testing machine. This is a two-screw machine. By rotation of

the screws about their axes, the pulling head is moved up and down. Suitable gearing gives a variety of speeds in either direction.

Fig. 12 shows an Olsen machine. This is generally a four-screw machine, sometimes three. In this type, the pulling head is made to move up or down by the rotation of large geared nuts stationary in the base of

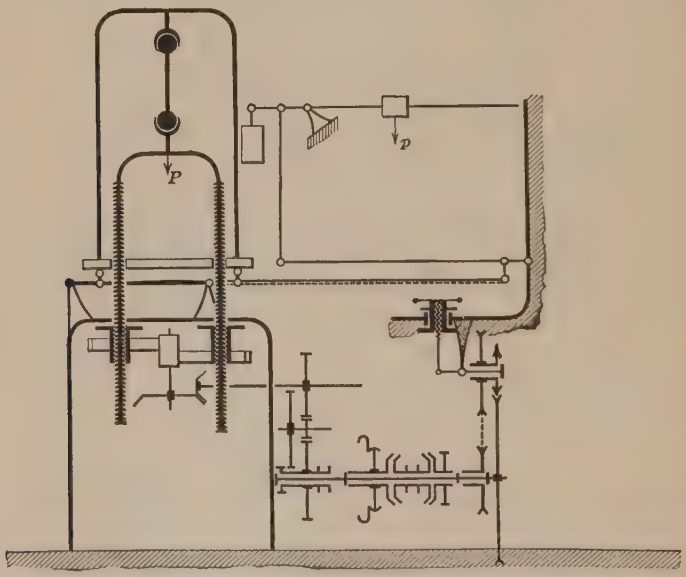

Fig. 12.—Diagrammatic view of an Olsen machine. (Modified from Marten's Handbook of Testing Materials.)

the machine. Through these nuts pass the main screws to which is attached the pulling head. The screws do not turn on their axes.

Hydraulic Machines.—Hydraulic machines, now becoming more popular, have many advantages in maintenance, steady loading, and in design of central

power plant for laboratory. These sometimes involve friction of packing in cylinder, which is not important in large machines, and which is obviated in small machines (Amsler) by use of a floating piston and a viscous fluid like castor oil Proper provision should be made to hold a steady load.

Fig. 13 shows the Amsler machine of small capacity.

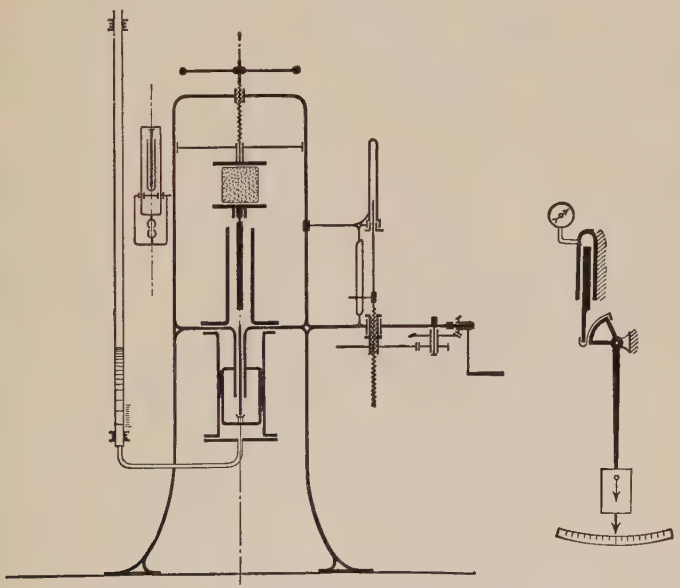

Fig. 13.—Diagram of Amsler testing machine. (From Wawrziniok.)

As shown, the machine is equipped with a hand pump and a mercury column load indicating device. To the right is shown the more common pendulum method of indicating load.

Fig. 14 is a diagrammatic sketch of a vertical Emery testing machine. The hydraulic cylinder A is fixed to

the frame *D* of the machine by the main rods *SS*. The plunger *B* is attached to the gripping apparatus. The weighing system is independent of the power system.

Impact Machines.—Impact testing machines are (1) with vertical guides, or (2) of pendulum type. Provision should be for measuring energy remaining in hammer after rupture of specimen. For this purpose, the hammer may fall on a spring (Fremont machine), or, a pencil attached to the hammer may write a velocity—displacement curve on a revolving drum (Turner machine). Method of release and hoist and mechanical details differ. Machines should be examined for: (a) fit of hammer in guides; friction; proportion of height of hammer to clear width between guides; proportion of weight of hammer to foundation; perfection of release; shape of striking edge. Hammer should deform specimen as a whole. Loss of energy at surface of impact and in foundation due to inertia of specimen should be small.

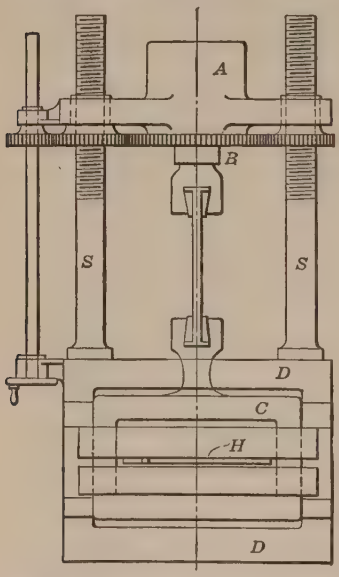

FIG. 14.—Diagram of a vertical Emery testing machine. (From Unwin.)

Fig. 15 illustrates the Turner vertical type of impact machine as used by the Forest Service in impact bending of small specimens. The pencil on the falling hammer makes a record on the revolving drum.

The drum record, Fig. 16, represents a test of a speci-

men broken in seven blows of increasing heights of hammer drop. The record gives the rebound heights and the deflection and set of the beam for each blow.

The drum record, Fig. 17, represents a test of a specimen broken in a single blow of the hammer. The drum velocity is given by the tuning fork record *T–T*. The

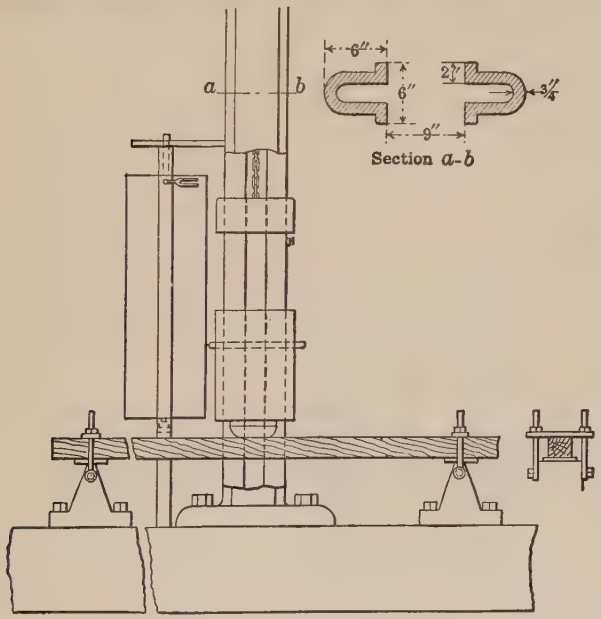

Fig. 15.—The Turner impact machine.

datum line *O–O* is the position of the hammer at instant of striking the specimen. The velocity of the hammer at that point may be obtained from the slope of the curve at the point of crossing. Distance up from the datum line represents free fall of the hammer. Distance down from the datum line to point of rupture *C* represents restrained fall of the hammer and deformation

of the specimen. Below the point of rupture, the hammer has free fall and the residual energy may be computed from the velocity as given by the curve slope.

Endurance Machines.—The ability of metals to withstand a rapid reversion of stress is an important property. Heat-treated automobile or other machine

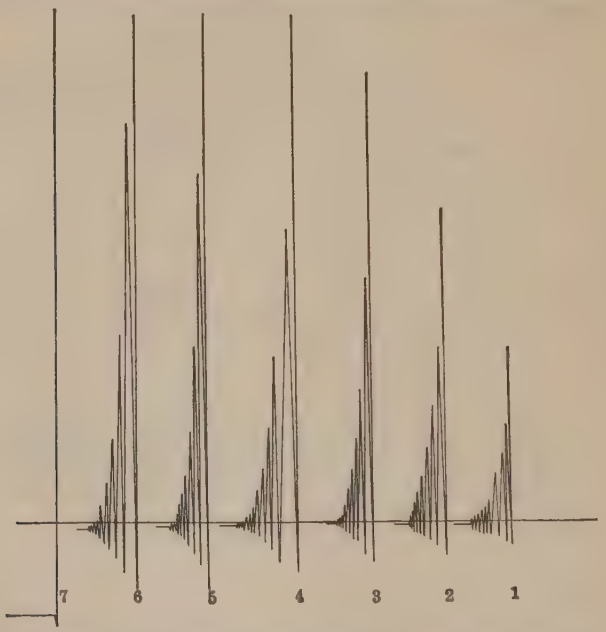

FIG. 16.—Drum record, Turner impact machine. Specimen broken by seven blows of hammer.

parts are tested for this quality by means of the endurance testing machine as shown in Fig. 18.

The test piece *A*, accurately machined to size and shape, is rigidly gripped in the pulley *B*. The pulley is seated and free to turn in ball bearings in the frame *F*. By means of the yokes *C*–*C* and their weight supporting

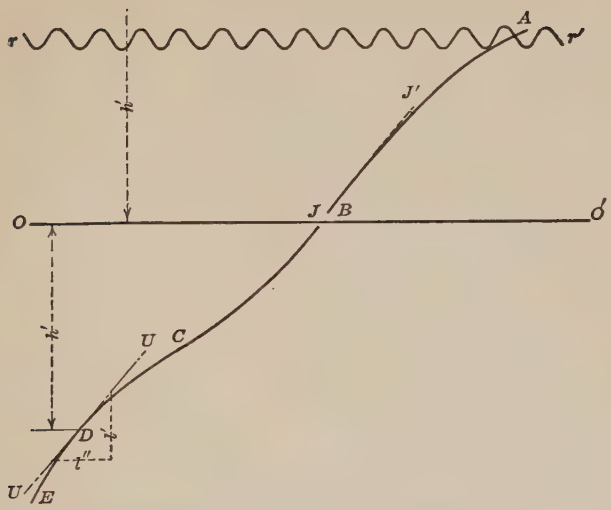

FIG. 17.—Drum record, Turner impact machine. Specimen broken in single blow.

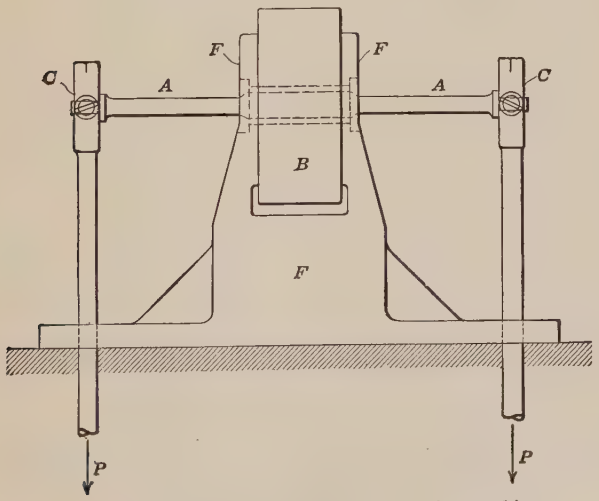

FIG. 18.—The White-Souther endurance testing machine.

standards, a load may be applied to each end of the test specimen. The pulley is made to rotate by belt connection to a motor. The speed of rotation is usually 1300 r.p.m. The stress in the top and bottom is alternately tension and compression in rapid succession. Complete failure occurs at the edge of the fillets after a varying number of revolutions and at a stress below the elastic limit of the metal.

Special Test.—*Hardness* is not well defined, nor uniformly measured. Unwin defines it as resistance to permanent or plastic deformation. In this definition it is distinguished from resistance to abrasion which is a compound of other qualities.

The best test for hardness is the Brinell Ball test. A hardened spherical ball (10 mm. diam.), is forced into a flat surface under a static pressure of 3000 kg. and 500 kg. for soft metals. The time of pressure should be at least 30 seconds. The specimen is 10 mm. thick and 35 mm. wide. Hardness = pressure / curved area of depression. A fixed ratio exists between hardness and tenacity of steels. Martens uses the depth of the impression. With balls 5 mm. in diameter the ratio of load to depth is constant within a depth range of 0.05 mm. The hardness number is the load necessary to indent material to 0.05 mm.

For instance, Brinell hardness number is as follows. Acid *Bessemer steel,* carbon 0.10, hardness number: rolled, 100; annealed, 96. *Basic Bessemer steel,* carbon 0.12, hardness number: rolled, 76; annealed, 81.

A more recently perfected method for determinations of hardness is by means of the *Scleroscope.* In this instrument the height of rebound of a small diamond pointed tup is taken as a measure of the hardness of the surface upon which it is caused to fall. The height of

drop is a fixed distance. The area of contact of the diamond point is so small that the metal upon which it strikes is stressed beyond the elastic limit.

The tensile strength of steel in pounds per square inch is obtained from the following equations.

TABLE 1.—EQUATIONS CONNECTING MAXIMUM STRENGTH AND BRINELL NUMBERS

Kind of steel	Equations
Carbon steel	$M = 0.73\ B - 28$
Nickel steel	$M = 0.71\ B - 32$
Chrome-vanadium steel	$M = 0.71\ B - 29$
Low-chrome-nickel steel	$M = 0.68\ B - 22$
High-chrome-nickel steel	$M = 0.71\ B - 33$
All steels grouped together	$M = 0.70\ B - 26$

TABLE II.—EQUATIONS CONNECTING MAXIMUM STRENGTH AND SCLEROSCOPE NUMBERS

Kind of steel	Equations
Carbon steel	$M = 4.4\ S - 28$
Nickel steel	$M = 3.5\ S - 6$
Chrome-vanadium steel	$M = 4.2\ S - 21$
Low-chrome-nickel steel	$M = 3.7\ S - 1$
High-chrome-nickel steel	$M = 3.7\ S - 3$
All steels grouped together	$M = 4.0\ S - 15$

M is maximum strength in 1000 pound per square inch units.

Reference.—Proceedings of the American Society for Testing Materials, 1915.

(c) WEIGHING MECHANISMS

1. The most common type is the lever system. These are illustrated in Figs. 11 and 12, diagrammatic representations of the Olsen and Riehlé testing machines.

All lever bearings and connections are hardened steel knife edges and plates. Load is indicated by the position of the poise p on the weighing beam.

2. A gage or manometric column indicates the pressure in the cylinder of hydraulic machines. Sometimes a pendulum lever is employed to serve the same purpose. These types are illustrated in Fig. 13 in the diagram of the Amsler machine.

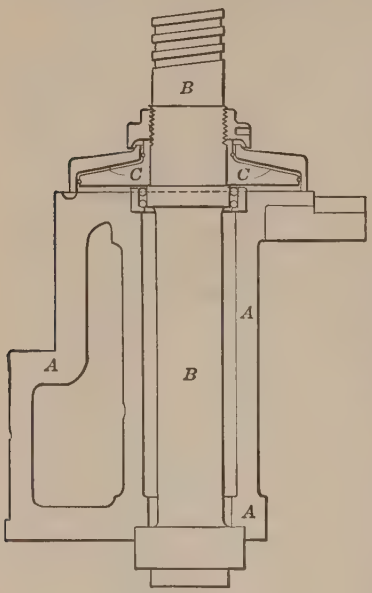

Fig. 19.

3. The pressure from the weighing table is transmitted to a hydraulic pad H, in Fig. 14, and thence to a manometric column or as in the Emery machine, to a separate lever system the fulchra of which are elastic plates.

4. A less common type is that in which the deformations of a portion of the frame of the machine are measured. The load is indicated by a measuring apparatus or by the change in volume of a hydraulic chamber which in turn is recorded on a fluid column. A diagrammatic view of this is shown in Fig. 19. The view shows one of the main rods B–B of the machine. This is fixed to the frame A of the machine. As the load comes on B, the deformation of B changes the volume of the chamber C–C, and is registered by a fluid column or

other convenient means. The load value of the column is determined by calibration.

EXTENSOMETERS AND OTHER DEFORMATION INSTRUMENTS

For the determinations of yield point of tension bars and deflection of beams, instruments reading to 0.01 in. are sufficient. But for the determination of elastic

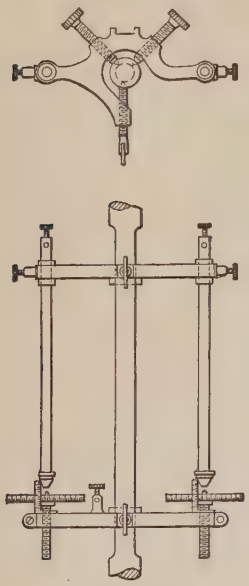

Fig. 20.—Yale-Riehlé extensometer.

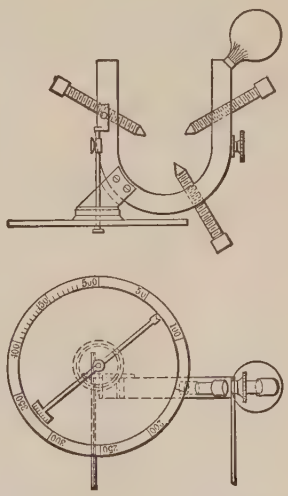

Fig. 21.—Johnson roller extensometer.

limit and modulus of elasticity and for many other purposes, deformation instruments reading to 0.0001 in. are required.

Extensometers may be classified:

1. *Micrometer screw*, see Fig. 20. These are very reliable for experienced laboratory use but are seldom

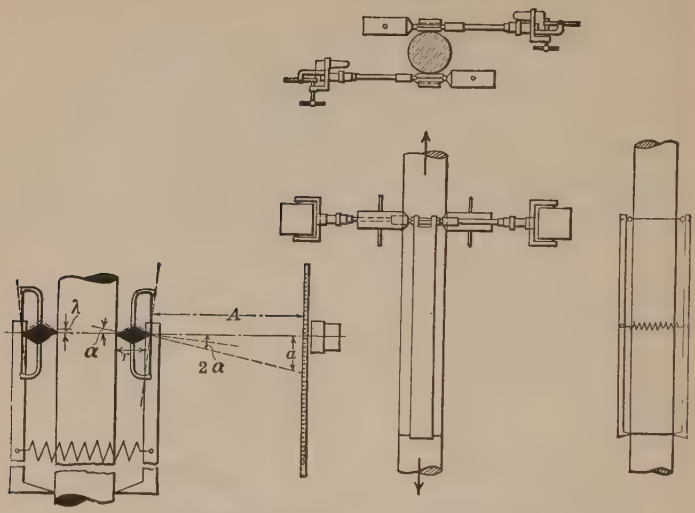

FIG. 22.—Marten's mirror extensometer.

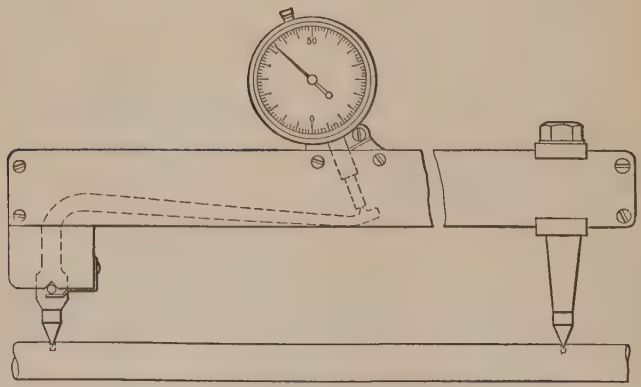

FIG. 23.—The Berry strain gage.

used for practical work. The contact of the micrometer points is best determined by means of an electric circuit and a telephone receiver in series.

2. *Roller dial* (Johnson type), See Fig. 21. A simple

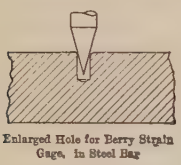

Fig. 23*a*.

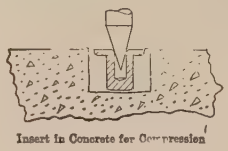

Fig. 23*b*.

type for laboratory use but unreliable on account of slippage at the roller. There is also error introduced by the wear of the roller. The readings are given direct on the dials.

3. *Roller mirror*, see Fig. 22. This is very delicate and reliable, but unsuited to student or routine work of the laboratory. The instrument must be used where there is little vibration or jar.

4. *Lever type*, examples of these are the Olsen Ewing and Berry. The last of these is particularly well adapted to a large variety of practical work both in the laboratory and in the field. In Fig. 23 is shown this instrument as made with contact points for use in reinforced concrete work and with adjustable gage length. The contact points are placed in small counter-bored holes in the test piece. In some cases, the instrument may be fixed and held in testing position throughout the loading,

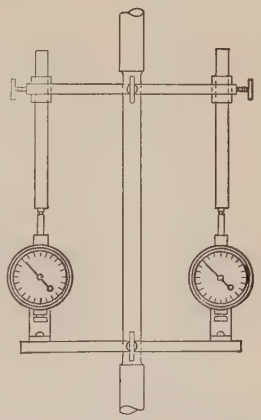

Fig. 23*c*.—Extensometer with Ames dials.

but generally it is removed after each reading is taken. In using the instrument, proper correction must be made for changes in temperature. The instrument reads directly to 0.0002 in. and closer by estimation of parts of a graduated division.

The following precautions are taken in using the Berry strain gauge:

1. The instrument is seated in the hole 5 times for an observed length.

2. A preliminary series is taken in new holes.

Fig. 24.—Diagrammatic representation of an Olsen deflection instrument.

3. After five sets of readings, the instrument is read on a standard bar to check up changes in the instrument.

4. To reduce observations for temperature changes, readings are made on a specimen which is without load, and which is exposed in the same manner as the specimen under test.

5. A single observer should make any set of readings and always in the same order.

6. The instrument should be applied at right angles to the bar and with uniform pressure.

Compressometers.—The simplest type of compressometer is shown by diagram in Fig. 24; this is a good practical instrument for rough work. It reads directly to 0.01 in. and by estimation to 0.001 in.

Fig. 25 illustrates an instrument designed for closer more accurate determinations. This compressometer needs very careful handling for the best results. Better service may be accomplished by replacing the electric bell by a telephone receiver, to give the micrometer contact. The instrument reads directly to 0.0001 in.

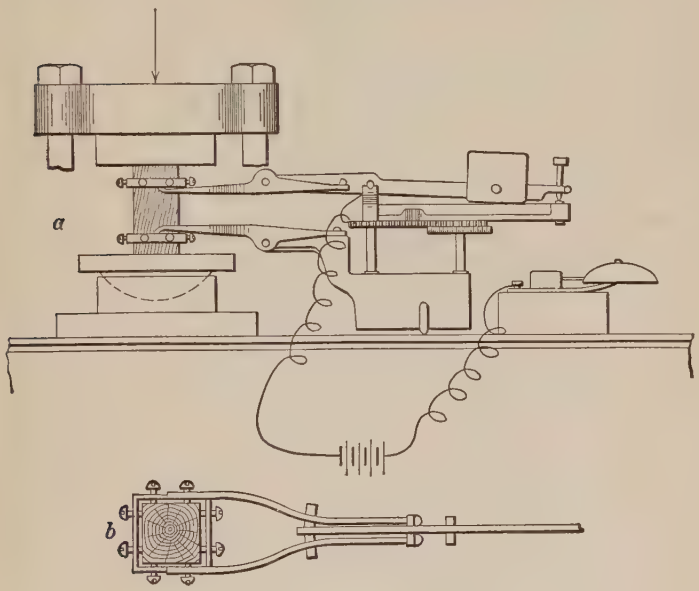

Fig. 25.—The Olsen compressometer.

A compressometer for short columns of timber which has been found very useful for student work by the authors, is shown in Fig. 26. Two yokes bearing Ames dials are attached to the specimen by four contact screws each. As the piece is deformed, the readings are given on both sides by the Ames dials. These read direct to 0.001 in. and by estimation to 0.0001.

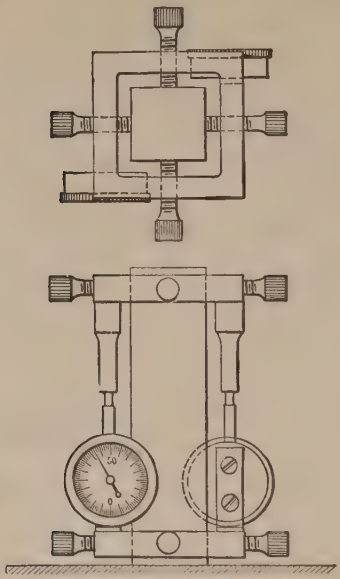

FIG. 26.—Author's compression instrument for short wood columns.

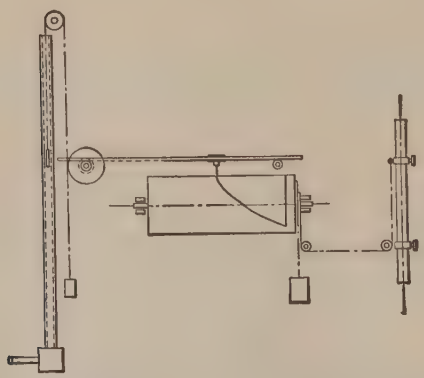

FIG. 27.—Autographic apparatus. (From Wawrziniok.)

Autographic Recording Apparatus.—A drum, Fig. 27, is fixed on the frame of the testing machine and put in gear with the specimen so that the rotation of the drum is proportional to the stretch of the specimen. A pencil in gear with the poise moves parallel to the axis of the drum. As the test proceeds, the diagram on the drum has abscissæ of deformation and ordinates of load. In some types, the poise is replaced by a spring at the end of the scale beam. As the load is applied the scale beam rises and the spring measures the load. The rise of the beam actuates the pencil on the drum. This type yields delicate load measurements. A home-made simple autographic device is made of a steam-engine indicator on this plan.

Autographic recorders are not suitable for the delicate measurements for elastic constants and are of limited use.

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EXPERIMENTS FOR ADVANCED WORK

The following list of experiments represents subjects for special tests to be carried out by the student. Some of these may also be made the subject of thesis investigation.

Iron and Steel.—Tension test of wire. Shearing tests of steel or iron. Tests of chains, hooks and rings. Tests of effect of shop methods on strength of steel and iron. Flexure test of I-beams. Tests of car bolsters, side frames, etc. Tests of flat springs in bending. Tests of built-up columns. Tests of metals in rapid reversion of stresses using White-Souther machine. Tests of various forms of joints. Tests of hardness of metals using Scleroscope. Tests of alloy steels. Tests of steel plates.

Wood.—Tension of various wood splices and joints. Indentation tests of wood. Wood in shear. Torsion of wood. Spike pulling tests of wood. Plate and washer bearing in wood. Tests of wood paving blocks. Tests of treated timbers.

Cement.—Determination of weight per cubic foot of cement. Effect of fineness of grinding on properties of

cement. Effect of varying amounts of gaging water. Effect of waterproofing methods upon strength and hardness. Tests for adulterants in cements. Effect of oils on properties of cements and cement mortars.

Concrete.—Strength of concrete with clay admixtures. Tests of concrete columns, plain and reinforced. Concrete in shear. Bond of steel in concrete. Tests of concrete T-beams. Concrete arches. Tests of porosity and permeability of concrete. Electrolysis of steel in concrete. Machine vs. hand mixed concrete.

Brittle Materials.—Compression tests, fire tests, freezing tests. Absorption tests. Test of patent roofing, flooring or other building material.

CHAPTER VII

INSTRUCTIONS FOR PERFORMING EXPERIMENTS

Article 1

TESTING MACHINES

Experiment A-1

Study of Testing Machines

In this experiment, the student becomes acquainted with various types of testing machines and gains skill in their operation.

References.—Standard Methods for Testing, E 1–18, A. S. T. M. Standards 1924. Johnson's Materials of Construction-rewritten by Withey and Aston. Page 49.

Materials.—No material to be tested.

Special Apparatus.—Various types of testing machines as assigned. For each machine assigned, tabulate: capacity of machine; name of builder; vertical or horizontal; number of screws; drive, *i.e.*, belt, direct connected motor, hydraulic?

Procedure.—(*a*) Study operation of machine. Each student should become familiar with operation of machines as he is responsible for breakage due to ignorance and carelessness.

(*b*) Tabulate number and direction and value of the various speeds with which moving head can be moved.

(*c*) Study and sketch the weighing table with lever system and weighing device. Sketch the various positions of control and speed levers.

General Rules for Operators.—1. Do not start machine into a continued motion without first ascertaining the direction and speed with which it will move. Extra precaution in this respect must be used if the movable head is near top or bottom of its range of movement.

2. Do not start the machine with too sudden a motion as there is danger of stripping a gear, throwing a belt, or injury to electrical equipment.

3. Do not reverse direction of motion or change speed without first stopping the machine.

4. Stop and start the motion with the lever provided on the machine, *not* with the counter-shaft shifter, nor with the electric switch.

5. When leaving the machine *always* see that the motion is stopped and counter-shaft is shifted to loose pulley.

Discussion of Results.—In the report, answer the following questions:

1. Why is there need for centering the specimen in the testing machine?

(*a*) With regard to effect on test piece.

(*b*) With regard to effect on machine.

2. Why can not the friction drive and main clutch drive be used simultaneously? (This refers to Olsen friction type of machines only.)

3. The slow speeds in the Olsen type of machine are sometimes obtained by a friction drive. In the Riehle type they are obtained by a system of gearing.

(*a*) State advantages and disadvantages of the friction drive for slow speeds.

(*b*) State advantages and disadvantages of the geared drive for slow speeds.

4. How is shock arising from rupture of specimen absorbed in the machine?

5. Where are the main wearing surfaces in the machine?

6. What is the purpose of (*a*) the counter-poise, (*b*) the counter-weight?

7. Upon what does the accuracy of a testing machine depend?

8. Upon what does the sensitiveness of a testing machine depend?

Experiment A-2

Calibration of Testing Machines

References.—Standard Methods for Testing, *E* 4-24. A. S. T. M. Standards, 1924. Johnson's Materials of Construction—Rewritten by Withey and Aston, page 98.

Testing machines should be calibrated at least once a year. This experiment will show the common methods of calibration.

I. Accuracy of Machine Over a Part of Its Range of Load.—The testing machine may be tested for accuracy by loading the weighing table with standard weights. The weights should be placed uniformly on the table and beam readings taken for the various weights applied.

This is the easiest and simplest manner of calibration of a testing machine but on account of the limited size of weighing table only a small part of the total capacity of the machine can be applied. However, the proportionality of the levers and weighing beam can be established and if the machine is correctly designed, the relation will hold constant for all loads. Auxiliary levers are also commonly used for this purpose.

II. Accuracy of a Machine Over a Part or All of Its Range of Load.—If the accuracy of the machine over its whole range is desired, a known load may be applied by a standard calibration bar whose modulus of elasticity has been accurately determined. The bar should be of sufficient strength so that the load desired should not stress it to or near the elastic limit. The bar should be carefully centered in the machine and gripped with the spherical bearing nut at the end. The length of the bar measured by the extensometer shall be sufficient that the smallest division on extensometer shall correspond to a difference in loading of 0.2 per cent. of the capacity of the machine or less. The extensometer shall read deformations to 0.0001 in. or less.

The percentage of error in the testing machine may be determined by comparison of the determined modulus of elasticity (see Experiment B–4) with the previously known correct modulus of the standard bar.

III. Tests of Sensitiveness of the Machine at Different Loads.—Place in the machine a tension bar or a compression block of such size that the maximum load will not stress it to the elastic limit. Load the specimen to $\frac{1}{10}$, $\frac{1}{2}$, and $\frac{9}{10}$ the capacity of the machine. At each load, balance the weighing beam and place standard weights upon the weighing table. A weight $\frac{1}{250}$ of the load applied on the machine should produce a readable movement of the beam.

Experiment A-3

Calibration of Extensometers or Other Measuring Device

Reference.—Johnson's Materials of Construction—Withey & Aston, page 100. Refer to Experiment B–4.

Case I.—Use a testing machine known to be accurate and a standard calibration bar whose modulus of elasticity is known. The extensometer to be calibrated is placed upon the bar in the usual manner and the modulus of elasticity determined in the usual way. The variation of the computed modulus from the correct modulus gives the error in the extensometer used.

Case II.—Using any bar and any machine determine the modulus with the extensometer to be calibrated and also with an extensometer which has previously been accurately calibrated. The variation in the modulus gives the error in the extensometer being calibrated. A convenient method is to use a bar of sufficient length to provide for both a standard extensometer and that to be tested. For greater refinement the extensometers may be interchanged in a second test.

Case III.—Direct comparison with any form of accurate measuring device may be made. Care must be taken to eliminate the effect of temperature changes, lost motion or other variables.

Article 2

IRON AND STEEL

Experiment B-1

Tension Test of Iron and Steel

The experiment is intended to represent the conditions obtaining in an ordinary commercial or acceptance test with the exception that the speed of descent of the pulling head of the testing machine is much slower than customary in commercial laboratories. The experiment will determine the strength and ductility of the material.

References.—Materials of Construction—Upton, Articles 48–75.

Johnson's Materials of Construction—Withey & Aston, page 104–110.

Tentative Methods for Testing, E 8-24T; and Standard Specifications for Materials, of Amer. Soc. for Testing Materials, 1924.

Material.—Bars of iron or steel as furnished.

Special Apparatus.—Micrometer calipers, scale, dividers.

Procedure.—1. Give specimen a number and record this.

2. With vernier or micrometer calipers determine the average dimensions of the cross section. Use average of three readings.

3. Lay off gage length of 8 in., each inch being marked by a light center punch mark.

4. Carefully balance the testing machine at zero of weighing beam after first loosening recoil nuts on weighing table. Then insert the test-piece in the wedges, being careful that the test-piece is centrally disposed in the axis of the machine, and that the specimen is gripped to within $\frac{1}{4}$ in. of the end gage marks. Tighten specimen in grips by applying a load of about 500 lb. Chalk a small area of the bar near the upper gage mark. *Before proceeding with the test allow the instructor to inspect the work.*

One student should insert one leg of a pair of dividers in the lower gage mark and scribe a line with the upper leg on the area previously chalked. Apply the load at a medium speed and operate the poise so as to keep the scale beam floating.

The requirements of the Amer. Soc. for Testing Materials as to speed are as follows:

Specified minimum tensile strength of material, lb. per sq. in.	Gage length, in.	Maximum crosshead speed, in. per minute, in determining	
		Yield point	Tensile strength
80,000 or under....	2	0.50	2 0
	8	2.00	6.0
Over 80,000.....	2	0.25	1.0
	8	0.50	2.0

The operator with the dividers should continue to scribe the line and notify the operator at the poise when the width of the scribed line increases perceptibly due to sudden increase in the rate of stretching of the test bar under the load. At this time the beam may be expected to drop suddenly and remain down for an interval; also rough mill scale will fall from the specimen. This increase in elongation without a corresponding increase in load is the "yield point." It is a point beyond the true elastic limit as obtained in experiment B-4.

During a further stretching of the bar the beam will again rise and should be kept floating up to the maximum load. At this maximum load the bar begins to neck in, the material becoming plastic at the point of the formation of the neck. Leave poise at the maximum load, do not attempt to get actual breaking load. The stretching of the specimen should be continued until fracture occurs. Record in data sheet the load at yield point and the maximum load.

Measurements after Tests.—Lay the broken ends of the bar together and determine the increase in elongation of the gage length. Measure the dimensions of the fractured area. Determine the rate of descent of the pulling head of the machine. Describe the appearance

of the fracture (see page 18) and determine the distance from the extreme gage point.

Calculations.—Calculate the ultimate tensile strength.

Calculate the stress at yield point.

Calculate the per cent. of elongation in gage length and per cent. of contraction of area at the fracture.

In case the fracture is outside the middle third of the gage-length, the per cent. of elongation is to be measured and computed although a retest may be allowed in certain cases. This should be noted in the report.

Discussion of Results.—Compare results with specifications and show in tabular form.

REPORT.—See instructions for writing reports, page 7.

Experiments B-2

COMMERCIAL TENSION TESTS OF CAST IRON OR STEEL CASTINGS

References.—Specifications of Amer. Soc. for Testing Materials. Standards 1924. Serial A 27–24 and A 48–18.

The materials in this test are generally as follows:

Cast Iron.—Specimen in the rough, no machining; standard arbitration bar machined to standard size.

Steel Casting.—Standard machined test-piece using 2-in. gage length.

PROCEDURE.—The method of test of cast iron is same as for Experiment B-1 except that maximum load only is obtained. The method of test of steel castings is the same as for Experiment B-1 except that a gage length of 2 in. is used.

Computations.—Make all computations as in regular test B-1, for steel casting specimens. For cast-iron specimens compute tensile strength.

DISCUSSION OF RESULTS.—Compare results with specifications and show in tabular form.

Experiment B-3

Autographic Tension Tests of Iron or Steel

This experiment may be performed by the instructor in front of the class to exhibit method used in commercial test B-1, and also by use of autographic diagram to show the general behavior of iron and steel when tested to rupture in tension.

Materials to be Tested.—The specimen should be a round bar of steel or iron.

Apparatus.—Besides the regular tension apparatus there should be the collars by which autographic apparatus is attached to specimen.

Procedure.—All dimensions and descriptions of specimens should be noted as in the regular tension test. After attaching the collars to the ends of the gage length, the specimen should be placed in the machine and a small initial load applied to hold it. Arrange the autographic apparatus so that the pencil is at the origin of diagram at zero load and zero stretch. Then apply the load continuously in a medium speed keeping the poise beam balanced. This may be done by the operator or by the mechanism in automatically balanced machines. Observe and record the load at yield point as given by the diagram, by drop of the beam and scaling of the specimen. Observe the maximum load as given by the beam and diagram.

Ascertain the elongation as given by the diagram and by actual measurement of specimen.

Compute all results as obtained in regular commercial tension test.

Experiment B-4

Tension Test with Extensometer

In this experiment the strength and elastic properties of iron and steel in tension are determined.

References.—Tentative Methods of Tension Testing in 1924 Standards of Amer. Soc. of Testing Materials. E 8–24.

Materials of Construction—Upton articles 39–48.

Johnson's Materials of Construction—Withey and Aston, page 111.

Material.—Wrought iron or steel.

Special Apparatus.—Extensometer reading to at least 0.0002 inches.

Note.—The extensometers are delicate instruments and must be handled carefully. Any roughness of usage or lack of delicacy in manipulation will result in unsatisfactory diagrams. Be sure that the test bar is straight.

Procedure.—Carefully measure and prepare each specimen as for regular tension test. See B–1. Tighten specimen in grips by applying an initial load equivalent to a stress of 2000 lb. per sq. in. (the machine having been previously balanced). Apply and adjust the extensometer, noting the length between the contact points, and (*after having had the apparatus inspected by the instructor*) proceed with the test. Apply load in increments equivalent to a stress of 4000 lb. per sq. in. for steel and 2000 lb. per sq. in. for iron and measure the total elongation at each load increment.

After reaching a sudden and large increase in elongation, remove the extensometer and apply load continuously until specimen is ruptured, keeping beam balanced. Record maximum load.

An actual stress instead of the commonly used nominal tensile stress may, if desired, be obtained by taking

readings of the new specimen diameters at each increment of load. This may be continued through to the breaking point and readings of total stretch made by dividers.

Construct a diagram with stress in *pounds per square inch* as ordinates and strain in *inches per inch* as abscissæ. Draw a *straight* line averaging the points up to the more rapid increase in elongation (the elastic limit), and, tangent to the straight line draw a smooth curve averaging the remaining points. Ordinarily, the straight line of plotted points will not pass through the origin. Draw through the origin a line parallel to the straight line of plotted points. This line represents the true relation between stress and strain. Mark the elastic limit where the strain ceases to be proportional to stress.

Calculations.—Calculate stress at elastic limit, ultimate tensile strength, per cent. elongation and contraction, modulus of elasticity, and modulus of elastic resilience.

The modulus of elasticity is the stress in pounds per square inch divided by the elongation in inches per inch at any point on the straight line through the origin. It is most convenient to select an abscissa of elongation of one part in 1000, and multiply the corresponding stress by 1000 to obtain the modulus of elasticity.

The modulus of elastic resilience is the amount of work done on each cubic inch of the specimen in deforming it to the elastic limit. It may be taken as the equivalent in inch-pounds of the area under the straight line up to elastic limit; or it may be calculated by formula.

Report.—The report should follow the standard form. It should be noted that this test is not a commercial acceptance test.

Experiment B-5

Experiment in Torsion

The object of this experiment is to study the behavior of materials under torsion, and to obtain such data as will enable the shearing strength of the material and its modulus of elasticity in shear to be computed.

References.—Materials of Construction—Mills. Articles 364.

Materials of Construction—Upton. Articles 76–110.

Johnson's Materials of Construction—Withey and Aston. Articles 140–142.

Bulletin No. 115, Engineering Experiment Station, Univ. of Illinois.

Material.—The material may be steel, iron, wood, or other material.

Special Apparatus.—Torsion Deformation instrument.

Procedure.—Carefully measure the dimensions of the cross-section and lay off gage length. Then adjust the specimen in the heads of the machine, being careful that the specimen is fixed in the axis of rotation of the machine. Then apply the deformation instrument to the specimen and adjust the clamps of the latter so that the center of the circle of the graduated arc will be in the axis of the machine. Measure the distance from the axis of the specimen out to the graduated arc. Apply a small initial moment of about 100 in. lb. and set to zero or record an initial reading of the graduated arc, and also the permanent scale on the twisting head of the machine. Measure the distance between grips.

Experiment.—Apply the loads by increment of 200 in. lb. Read on the graduated arc the movement of the

pointer in inches for each increment. When the increase in the angle of torsion is found to be rapid, the elastic limit has been reached. The graduated arc and index should then be removed.

If only the elastic properties of materials are to be determined the specimen may be removed. Ordinarily the tests are to be continued until the specimen is ruptured. Read load every 180° turn. The whole angle of the twist is read from the fixed scale on the movable head of the machine. The scale beam should be kept balanced and the maximum load determined.

Curves.—Plot diagrams to suitable scales with the twisting moment in inch-pounds as ordinates and the deformation in radians per gage length as abscissæ. One of these curves will be drawn with the magnified abscissa and will show the points up to the elastic limit. The other curve will be on a small scale and will show the complete angle-moment diagram up to the rupture. As in other experiments, the straight line portion in the beginning should pass through the origin. If it does not, a straight line parallel to the straight line passing through the plotted points should be drawn through the origin and terminating at the elastic limit. Mark the points corresponding to the elastic limit and maximum load on the curve.

Calculations.—Compute (1) the shearing stress developed at the elastic limit and the maximum load, using formula. (2) Calculate the modulus of elasticity in shear. (Use the coordinates of any point on the corrected curve of the magnified scale.) (3) Compute also the elastic resilience per cubic inch.

Report.—The report should follow standard form on p. 7.

Experiment B-6

Test of Wire Cable

The purpose of this test is to determine the strength of a wire cable by testing the separate wires.

References—Johnson's Materials of Construction, pages 94 and 669.

Material.—One piece of a wire cable about one foot long. Be sure it is a full strand.

Procedure.—Note strands in rope, number of turns per foot in strand, number of turns per foot in cable. Untwist wires of strand, note number of wire, determine the diameter in two places on each. Test each wire to rupture. Note breaking load. Calculate. 1. Tensile strength of wires in pounds per square inch. 2. Strength of cable. 3. Would cable be as strong as the sum of all the strengths of the individual wires? Why?

Tests of wire rope as a whole may be made by properly brooming the ends, cleaning and tinning the wires and casting in babbitt metal in conical sockets so designed as to be gripped or held in the heads of the testing machine.

The wires may be cleaned by dipping in gasolene followed by hot caustic potash. After cleaning, the wires should be dipped in zinc chloride and then tinned in molten babbitt.

Report above items and submit in regular form.

Note.—Tabulate the number of wires whose strengths are within 5 per cent., 10 per cent., 15 per cent., 20 per cent, 25 per cent. of average strength, etc.

Experiment B-7

Compression of Helical Spring

References.—Unwin's Strength of Materials.

1924 Standards, Amer. Soc. for Testing Materials, serial A 61–16, page 120.

Object.—A helical spring under load is a case of torsion. Springs are tested to determine their capacity and travel. The modulus of elasticity in shear and the resilience of the springs may be computed.

Material.—Two helical springs.

Apparatus.—Deflection instrument.

Procedure.—Measure height of spring, diameter of coil, diameter of wire and number of free turns. Place spring in testing machine as for compression. Determine the following items as prescribed by the Amer. Soc. for Testing Materials:

(*a*) *Solid Height.*—The solid height is the perpendicular distance between the plates or the testing machine when the spring is compressed solid with a test load at least $1\frac{1}{4}$ times that necessary to bring all the coils in contact. The solid height shall not vary more than $\frac{1}{8}$ in. from that specified.

(*b*) *Free Height.*—The free height is the height of the spring when the load specified in Paragraph (*a*) has been released, and is determined by placing a straight edge across the top of the spring and measuring the perpendicular distance from the plate on which the spring stands to the straight edge, at the approximate center of the spring. The free height shall not vary more than $\frac{1}{8}$ in. from that specified.

(*c*) *Loaded Height.*—The loaded height is the distance between the plates of the testing machine when the specified working load is applied. The loaded height

shall not vary more than $\frac{1}{8}$ in. over nor more than $\frac{1}{16}$ in. under that specified.

(*d*) *Permanent Set.*—The permanent set is the difference, if any, between the free height and the height (measured at the same point and in a similar manner) after the spring has been compressed solid three times in rapid succession with the test load specified in Paragraph (*a*). The permanent set shall not exceed $\frac{1}{32}$ in. Apply 100 lb. initial load; adjust the deflectometer. The load is applied by increments of pounds taking travel or compression at each load.

Plot load-deformation curve, and energy-travel curve.

Calculations.—1. Load at instant spring becomes solid (Maximum load). 2. Fiber stress in shearing at maximum. 3. Resilience per cubic inch at maximum. 4. Modulus of elasticity in shear.

Report should cover above elements and appear in general form.

Experiment B-8

Effect of Overstrain on Yield Point of Steel

Reference.—Moore's Materials of Engineering, page 35. Johnson's Materials of Construction—Withey and Aston, page 661.

Material.—Steel bar about 18 in. long.

Apparatus.—Extensometer.

Procedure.—Measure the dimension of the test piece and lay off a gage length of 8 in., marking each inch with a light prick punch mark. Calculate probable elastic limit. Apply load to about two-thirds of this amount, keeping beam carefully balanced. Apply load again until past yield point. Release as before. Repeat three or four times. Take all measurements as in B-4.

Note slope of curves.

REPORT.—Report should include analysis and discussion of results.

Experiment B-9

FLEXURE TEST OF CAST IRON OR STEEL

This experiment is intended to show method of testing cast iron or steel in flexure and to give data for the computation of transverse strength.

References.—Standards 1924 of Amer. Soc. for Testing Materials, Serial A 48–18.

Mills Materials of Construction, Art. 365 and 401.

Johnson's Materials of Construction—Withey and Aston, Art. 764.

Materials.—A round, or rectangular bar of iron or steel of sufficient length to give a span of at least 10 in.

The "Arbitration Bar" of cast iron is a bar $1\frac{1}{4}$ in. in diameter and 15 in. long. The bars are in the rough and molded with special treatment.

Special Apparatus.—A deflectometer reading to 0.001 in.

Procedure.—Arrange testing machine for transverse test with supporting knife edges at least 10 in. apart (12 in. for the "Arbitration Bar." See Appendix III). Compute breaking load (using table of strengths in appendix) and use an increment of load equal to $\frac{1}{15}$ of the breaking load. Measure deflection at center of span for each increment of load.

Results and Conclusions.—The report should be written in usual form and contain a comparison with specifications or other reliable data. Show load-deflection curve.

Experiment B-10

Flexure Test of Brake Beam

Brake beams are required to pass certain specifications of the Master Car Builders' Association.

Reference.—Report of Master Car Builders' Association, Vol. 52, 1918.

Material.—Any brake beam complying with the M. C. B. Standard Specifications for dimensions.

Deflection Measurement Tests.—After the beam is mounted in a testing machine a load equal to Deflection Load (See Table 1) will be applied and then reduced to 500 lb. After the Deflection Load is reapplied the deflection shall not be more than 0.07 in. The beam will then be loaded to the Set Load as shown in Table 1 and released to 500 lb., when the beam shall not show a set greater than 0.01 in.

Table No. 1

M. C. B. beam No.	Deflection load	Set load	Ratio
1	6,500	14,000	47
2	15,000	27,000	55
3	18,000	30,000	60
4	24,000	36,000	66.7
5	30,000	42,000	71.2
6	36,000	48,000	75

Results.—Compare with M. C. B. specifications. See general form of report.

Experiment B-11

Special Hardness Tests

Purpose.—The object of this test is to determine the scleroscope and Brinell hardness numbers of a steel

bar and to compare the strengths as calculated from these hardnesses with the actual tensile strength.

References.—Manual, page 34, Moore's Materials of Engineering. American Society for Testing Materials Proceedings.

Material.—Steel bar with a machined surface at one end.

Procedure. 1. *Shore Scleroscope Test.*—Clamp the standard hardness bar in place and take a reading by quickly pressing the bulb of the apparatus. Read the top of the hammer at the height of rebound and "*Never allow the hammer to strike more than once on the same spot, not too near the same, for the reading will be of no value as a measure of hardness.*"

2. *Olsen Brinell Test.*—a. With the pressure gage reading zero and the escape valve to the pressure cylinder open, clamp the machined surface of the specimen against the ball by use of the hand wheel.

b. Close the escape valve to the pressure cylinder and operate the pump until the full pressure is on the specimen. This is indicated by the floating of the check test weights. Leave the pressure on for the full 30 seconds.

c. Open the escape valve slowly and allow the pressure to return to zero. Remove the specimen by using the hand wheel.

d. Measure the diameter of the impression with the microscope furnished for making the test. With the diameter of the impression as a key the Brinell hardness number may be found from the wall chart near the machine. The relation between the Brinell hardness number and the tensile strength may be found on page 35.

3. *Tension Test.*—Test the bar for ultimate strength as in experiment B-1.

Experiment B-12

Determination of Stress by Means of the Strain Gage.

Reference.—Proc. Amer. Soc. for Testing Materials, 1913, page 1019 and others.

Material.—4″–7½ lb. I-beam.

Special Apparatus.—8″ Berry or Olsen Strain gage and standard bar.

Method.—The I-beam is loaded at the third points in flexure. Four gages are located on top of compression flange, and four on bottom of tension flange. These should be numbered from 1 to 8. Each person should take a complete series of strain gage readings when a total load of 500 lbs., 3500 lbs., and 6500 lbs. is applied to the beam.

Curves.—Plot a load deflection curve. Plot three curves on same sheet to same scale with load as ordinates and stresses as abscissae, the first showing extreme fiber stresses in compression as computed from gage readings; the second showing extreme fiber stresses in tension as computed from gage readings; the third showing theoretical extreme fiber stresses.

Report.—A concise engineering report is desired. Suggested contents: (a) Short description of instrument and its use. (b) Correction for changes in instrument during use. (c) Method of obtaining actual stresses from strain gage reading. (d) Compute stresses of test beam from laws of flexure. (e) Comparison (c) and (d) by means of tables and curves. (f) Distribution of stress over flanges by diagram. (g) Discussion and conclusions.

Article 3
TESTS OF WOOD

Experiment C-1

INSTRUCTIONS FOR LABORATORY EXERCISE FOR THE IDENTIFICATION OF WOODS

Purpose.—The purpose of this experiment is practice in identification of timbers by appearance.

References.—Identification of the Economic Woods of the United States—Samuel T. Record.

Bulletin No. 10 of the Forest Service; and a pamphlet entitled "Trees of the United States Important in Forestry."

Material.—The material will consist of specimens exhibited in the Laboratory for Testing Materials, numbered in consecutive numbers, including the common species of soft and hard woods; a key to these.

Outline of Work.—1. Take the key to these woods and examine each in turn with reference to the material in the text mentioned above. Make notes concerning (*a*), in the hardness of the material, (*b*) the character of the grain as shown on the cross section, (*c*), the kind and distribution of pores, (*d*), the relative proportion of spring and summer wood in the rings, (*e*), color and appearance of the surface, together with whatever other external features will aid in the identification. Additional short sections of the specimens on exhibit will be found hanging behind the large specimens. The large specimens should not be damaged, but the smaller duplicates may be cut with a jack knife to determine their working qualities.

After this work is performed, the instructor will test the knowledge of the student by asking him to identify selected specimens of the woods.

Report.—Report will describe six selected species, together with drawings of the structure of the wood as seen through the magnifying glass. The uses and sources of supply of the wood will also be described.

Six Selected Specimens

I. White Oak.
II. Red Oak.
III. Yellow Pine (Longleaf).
IV. White Pine.
V. White Hickory.
VI. Hard Maple.

Experiment C-2

Compression of Short Wood Columns Parallel to Grain

References.—Johnson's Materials of Construction—Withey & Aston, page 196.

Forest Service Circular No. 213.

Timber, its Strength, Seasoning and Grading—Betts, page 10, Table 3.

U. S. Department of Agriculture Bulletin No. 556.

A.S.T.M. Tentative Methods D143–24T.

This experiment may be preceded by the flexure of short beams C-5 and the material for this test taken from ends of short beams used in C-5.

Materials to be Tested.—The columns to be tested are to be about 2 in. × 2 in. × 8 in. They should be surfaced four sides with ends squared and smooth cut.

The wood may be in the air dry, kiln dry, green, or resoaked condition as to moisture content.

Apparatus.—A compressometer reading to at least 0.0001 in. Collars, by means of which compressometer is attached to specimen. See Fig. 26.

Deformations are more simply but less accurately measured by resting the measuring apparatus on the weighing table, and determining the travel of the movable head of the testing machine.

Procedure.—Ascertain and record the following data: (*a*) Kind of wood. (*b*) Per cent. of heart and sap wood. (*c*) Per cent. of summer wood. (*d*) Annual rings per radial inch. (*e*) Dimensions of the test piece. (*f*) Note defects.

Lay off the gage lengths, usually 6 in., on specimen and attach the collars at the ends of gage length. Place in the machine on the spherical bearing plate and center.

Apply initial load equal to the first increment (generally 1000 lb. for the hard woods). After adjusting the compressometer to a zero reading apply the load by increments until the elastic limit has been reached. This is seen from the increased increments of deformation at that point. Take a reading for at least two loads beyond the elastic limit.

Remove the compressometer and loosen the collars and then, applying the load continuously in the slow speed, obtain the maximum load. Carry the loading far enough to develop the character of fracture.

Computations.—Plot a diagram for each specimen with load in pounds as ordinates and deformation in inches as abscissæ. If the straight portion of the curve below the elastic limit does not pass through the origin, draw a parallel straight line through the origin. The load at elastic limit should be taken from this curve.

Compute.—(*a*) Unit compressive strength at elastic limit. (*b*) Compressive strength at maximum load. (*c*) Modulus of elasticity. (*d*) Modulus of elastic resilience.

The report should show sketches of fractured specimens.

Experiment C-3

Compression of Wood Perpendicular to Grain

This experiment may be preceded by C-5 and the material for this test may be taken from ends of beams used in C-5.

References.—See references to C-2.

Materials.—Blocks about 2 in. × 2 in. × 8 in. finished four sides.

The wood may be in the air dry, kiln dry, green or resoaked condition as to moisture content.

Apparatus.—A compressometer reading to 0.0001 in. A rectangular finished loading plate of cast iron or other metal 1 in. × 2 in. × 4 in.

Procedure.—Ascertain and record the following data: (*a*) Kind of wood. (*b*) Per cent. of heart and sap. (*c*) Per cent. of summer wood. (*d*) Annual rings per inch. (*e*) Dimensions of the block.

Place the specimen in the machine flatwise and center. The loading plate should be placed on the specimen flatwise and long axis perpendicular to long axis of specimen. Apply an initial load equal to the first increment of load.

Apply the load continuously, preferably by means of a spherical bearing directly upon the loading plate, taking readings of compressions for increments of load as follows: 800 lb. for heart hard woods, and 400 lb. for sap hard woods and 200 lb. for soft woods.

The loading should be carried to the elastic limit of the specimen. This may be seen from the increased increments of deformation at that point. Do not try to obtain maximum load as there is none in specimens of this size across grain.

Computations.—Plot a diagram for each specimen with load in pounds as ordinates and deformations in inches as abscissæ. The load at elastic limit should be taken from this curve. Compute unit compressive strength at elastic limit.

Experiment C-4

Tests of Wood Columns

In this experiment, the behavior of the wood under column action may be learned together with constants of strength of columns.

Reference.—Johnson's Materials of Construction, page 16.

Material.—Small wood columns of any species. They should be dressed on four sides, true to dimensions and have a slenderness ratio between 20 and 150. At least two columns of each species of wood of different slenderness ratios should be available for test.

Procedure.—Ascertain and record all data as in Experiment C-2.

Stretch a wire along the neutral axis of the narrow side of column. Any convenient method may be used to measure side bending or buckling of the columns. Great care must be taken in centering specimen in the machine. Apply small initial load and then determine zero reading of deflector at center of column.

Apply load at a slow uniform speed and determine the maximum load the column will stand.

The condition at ends may be one of the two cases: flat ends, hinged ends. Test in each condition of ends, two columns of different slenderness ratios.

Calculations.—Compute values of S and ϕ for each species of wood and for each condition of ends. Use Rankine's formula. The value S, unit compressive strength, is best obtained by method C-2 on specimen cut from the long column.

Experiment C-5

Flexure Test of Small Wood Beams

This experiment gives the strength and elasticity of woods as shown in tests of small specimens.

Johnson's Materials of Construction—Withey and Aston, page 196.

Forest Service Circular No. 213.

Timber, its Strength, Seasoning and Grading. Betts, page 10, Table 3.

U. S. Department of Agriculture Bulletin No. 556.

A.S.T.M. Tentative Methods D143–24T.

Materials.—Two or more pieces of wood of oak, pine or other species. The size is about 2 in. × 2 in. × 30 in. The specimens are finished on four sides. The wood may be in the air dry, kiln dry, green, or re-soaked condition as to moisture content.

Apparatus.—Deflection Instrument reading to 0.01 in.

Procedure.—Ascertain and record the following data: (*a*) Kind of wood. (*b*) Per cent. heart wood and sap wood. (*c*) Per cent. summer wood. (*d*) Annual rings per radial inch. (*e*) Dimensions of piece. (*f*) Weight of specimen in grams. (*g*) Note defects such as knots, season checks, rot, etc.

On one side of specimen mark the neutral axis and span-length and mid-span lines. The span to be used is . . . in.

Place the beam upon the knife edge supports, using short iron plates to prevent local crushing of the wood and binding between the supports. If there is clearance enough, two plates with two rollers between should be used at each support to allow freedom of bending. Apply an initial load of 100 lb. and adjust deflection instrument to read zero. See Fig. 8.

NOTE.—Common methods of measuring deflections are as follows:

(*a*) Place a deflectometer on base of machine under center of beam. (Fig. 24.) This is equivalent to having a scale or vernier attached to the loading yoke as in some special flexure machines.

(*b*) Hang a special deflectometer on pins or tacks in the neutral axis over supports and attach the wire of needle to tack in neutral axis at mid-span. See that the wire is vertical. (Fig. 8.)

(*c*) Stretch a wire between tacks over supports and scale attached to beam at mid-span. A mirror or polished scale should be used so that image of wire may be seen, thus avoiding parallax. (Fig. 9.)

Of these methods, the second is the most accurate but the first and last may be used in certain work. Apply the load continuously at a slow speed and take readings of deflection for increments of 100 lb. load. If care is exercised, in keeping the beam balanced near the point of failure, it will be possible to read the correct load and deflection at failure even though this does not occur at one of the regular load increments. After obtaining the maximum load, carry the loading only far enough to develop the point and character of fracture.

Sketch and describe fractures.

Moisture Content of Specimen.—Cut from the specimen near the point of failure a disk about 1 in. in thickness. Trim off all loose wood and weigh on sensitive balances. This moisture disk is to be oven-dried and again weighed. The loss in weight expressed as a per cent. of dry weight gives the per cent. of moisture in beam.

For Tests in Compression.—Saw from the beam already tested, two test pieces 8 in. in length to be used in Experiments C-2 and C-3.

Computations.—Plot a diagram with load in pounds as ordinate and deflection in inches as abscissæ. Draw the correction curve through the origin, if necessary, The load at elastic limit is taken from this curve.

Compute.—(*a*) Fiber stress at elastic limit. (*b*) Modulus of Rupture. (Fiber stress at maximum load.) (*c*) Modulus of Elasticity. (Use corrected deflections.) (*d*) Elastic Resilience per cubic inch. (*e*) Rupture

work per cubic inch. (*f*) Per cent. moisture. (*g*) Specific gravity.

Discussion of Results.—See general form of report.

Experiment C-6

Flexure Test of Large Wood Beams

The strength and elasticity of timber in full size specimens are determined in this test.

References.—Circular No. 38, of Forest Service.

Johnson's Materials of Construction—Aston and Withey, Articles 230–232. Bulletin of Forest Service No. 108.

A.S.T.M. Tentative Method D198–24T.

Material.—Full size specimens of any wood in which span length does not exceed 16 ft. The specimens may be finished or in the rough but should be sawed true to size and squared.

Procedure.—Ascertain and record all data as in Experiment C-5. The method of testing is the same as in C-5 except that the load is applied at the third points, to approach as nearly as possible to conditions of uniform loading. Moisture content is obtained as in C-5.

Computations.—Make all computations as in Experiment C-5.

Discussion of Results.—Compare results with average of other tests upon same and different kinds of timber.

Experiment C-7

Impact Test of Wooden Beams

In determining the relative brittleness of different timbers, tests in impact bending will be made.

Reference.—Circular No. 38, Forest Service.

Material.—Two 2 in. × 2 in. × 30 in. sticks. Any wood.

Special Apparatus.—Impact machine.

Procedure.—The resistance of a specimen of wood under impact is usually determined by dropping a given weight from successively increasing heights. The successive amounts of deformation and set of the specimen and rebound of the hammer are recorded on the drum. The elastic strength of the specimen is fixed at that limit at which the deflection suddenly increases. At this limit a sudden increase in the set of the specimen, as well as a maximum amount of rebound of the hammer, usually occurs.

In making the test the hammer is allowed to rest upon the upper surface of the specimen, and a zero or datum line is drawn on the drum. The deflection under the dead load of the hammer is obtained from a static cross-bending test of similar material. A corrected zero line can thus be drawn. Then blows of a weight dropped from increasing heights are delivered to the specimen, and records taken on the drum. A sample record is seen in Fig. 16.

The height of the drop at which any rupture of the specimen occurs is noted, together with other phenomena of test. Sample log sheets and calculations will be found in the Appendix of Circular 38, Forest Service.

The machine is calibrated in advance to determine the proportion of the height of fall which is not effective because of friction and lag of magnet.

Occasionally the beam is ruptured under a single blow of the hammer falling from a height greater than that necessary to rupture the specimen. In this case the resid-

ual energy resident in the hammer, after rupture of the specimen must be determined in order that the amount of energy used up in rupturing the specimen may be known.

The zero or datum line is determined as before, the hammer is released from a height greater than that necessary to rupture the specimen, and a record is taken of the circumstances of the impact. The tuning fork must be held on the drum during impact. A sample record is shown in Fig. 17.

Calculations.—Determine rupture-work, height of drop at elastic limit and maximum. Specific gravity, etc.

Article 4

TESTS OF CEMENTS[1]

VI. Sampling

Number of Samples

16. Tests may be made on individual or composite samples as may be ordered. Each test sample should weigh at least 8 lb.

17. (*a*) *Individual Sample.*—If sampled in cars one test sample shall be taken from each 50 bbl. or fraction thereof. If sampled in bins one sample shall be taken from each 100 bbl.

(*b*) *Composite Sample.*—If sampled in cars one sample shall be taken from one sack in each 40 sacks (or 1 bbl. in each 10 bbl.) and combined to form one test sample. If sampled in bins or warehouses one test sample shall represent not more than 200 bbl.

[1] Authorized Reprint from the Copyrighted A. S. T. M. Standards (1924), American Society for Testing Materials, Philadelphia, Pa.

Method of Sampling

18. Cement may be sampled at the mill by any of the following methods that may be practicable, as ordered:

(*a*) *From the Conveyor Delivering to the Bin.*—At least 8 lb. of cement shall be taken from approximately each 100 bbl. passing over the conveyor.

(*b*) *From Filled Bins by Means of Proper Sampling Tubes.*—Tubes inserted vertically may be used for sampling cement to a maximum depth of 10 ft. Tubes inserted horizontally may be used where the construction of the bin permits. Samples shall be taken from points well distributed over the face of the bin.

(*c*) *From Filled Bins at Points of Discharge.*—Sufficient cement shall be drawn from the discharge openings to obtain samples representative of the cement contained in the bin, as determined by the appearance at the discharge openings of indicators placed on the surface of the cement directly above these openings before drawing of the cement is started.

Treatment of Sample

19. Samples preferably shall be shipped and stored in air-tight containers. Samples shall be passed through a sieve having 20 meshes per linear inch in order to thoroughly mix the sample, break up lumps and remove foreign materials.

VII. Chemical Analysis

Loss on Ignition

20. One gram of cement shall be heated in a weighed covered platinum crucible, of 20 to 25 c.c. capacity, as follows, using either method (*a*) or (*b*) as ordered:

(*a*) The crucible shall be placed in a hole in an as-

bestos board, clamped horizontally so that about three-fifths of the crucible projects below, and blasted at a full red heat for 15 minutes with an inclined flame; the loss in weight shall be checked by a second blasting for 5 minutes. Care shall be taken to wipe off particles of asbestos that may adhere to the crucible when withdrawn from the hole in the board. Greater neatness and shortening of the time of heating are secured by making a hole to fit the crucible in a circular disk of sheet platinum and placing this disk over a somewhat larger hole in an asbestos board.

(*b*) The crucible shall be placed in a muffle at any temperature between 900 and 1000° C. for 15 minutes and the loss in weight shall be checked by a second heating for 5 minutes.

21. A permissible variation of 0.25 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 4 per cent.

Insoluble Residue

22. To a 1-g. sample of cement shall be added 10 c.c. of water and 5 c.c. of concentrated hydrochloric acid; the liquid shall be warmed until effervescence ceases. The solution shall be diluted to 50 c.c. and digested on a steam bath or hot plate until it is evident that decomposition of the cement is complete. The residue shall be filtered, washed with cold water, and the filter paper and contents digested in about 30 c.c. of a 5 per cent. solution of sodium carbonate, the liquid being held at a temperature just short of boiling for 15 minutes. The remaining residue shall be filtered, washed with cold water, then with a few drops of hot hydrochloric acid, 1:9, and finally with hot water, and then ignited at a red heat and weighed as the insoluble residue.

23. A permissible variation of 0.15 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 0.85 per cent.

Sulphuric Anhydride

24. One gram of the cement shall be dissolved in 5 c.c. of concentrated hydrochloric acid diluted with 5 c.c. of water, with gentle warming; when solution is complete 40 c.c. of water shall be added, the solution filtered, and the residue washed thoroughly with water. The solution shall be diluted to 250 c.c., heated to boiling and 10 c.c. of a hot 10-per cent. solution of barium chloride shall be added slowly, drop by drop, from a pipette and the boiling continued until the precipitate is well formed. The solution shall be digested on the steam bath until the precipitate has settled. The precipitate shall be filtered, washed, and the paper and contents placed in a weighed platinum crucible and the paper slowly charred and consumed without flaming. The barium sulfate shall then be ignited and weighed. The weight obtained multiplied by 34.3 gives the percentage of sulfuric anhydride. The acid filtrate obtained in the determination of the insoluble residue may be used for the estimation of sulfuric anhydride instead of using a separate sample.

25. A permissible variation of 0.10 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 2.00 per cent.

Magnesia

26. To 0.5 g. of the cement in an evaporating dish shall be added 10 c.c. of water to prevent lumping and then 10 c.c. of concentrated hydrochloric acid. The liquid shall be gently heated and agitated until attack is

complete. The solution shall then be evaporated to complete dryness on a steam or water bath. To hasten dehydration the residue may be heated to 150 or even 200°C. for one-half to one hour. The residue shall be treated with 10 c.c. of concentrated hydrochloric acid diluted with an equal amount of water. The dish shall be covered and the solution digested for ten minutes on a steam bath or water bath. The diluted solution shall be filtered and the separated silica washed thoroughly with water.[1] Five cubic centimeters of concentrated hydrochloric acid and sufficient bromine water to precipitate any manganese which may be present, shall be added to the filtrate (about 250 c.c.). This shall be made alkaline with ammonium hydroxide, boiled until there is but a faint odor of ammonia, and the precipitated iron and aluminum hydroxides, after settling, shall be washed with hot water, once by decantation and slightly on the filter. Setting aside the filtrate, the precipitate shall be transferred by a jet of hot water to the precipitating vessel and dissolved in 10 c.c. of hot hydrochloric acid. The paper shall be extracted with acid, the solution and washings being added to the main solution. The aluminum and iron shall then be reprecipitated at boiling heat by ammonium hydroxide and bromine water in a volume of about 100 c.c., and the second precipitate shall be collected and washed on the filter used in the first instance if this is still intact. To the combined filtrates from the hydroxides of iron and aluminum, reduced in volume if need be, 1 c.c. of ammonium hydroxide shall be added, the solution brought to boiling, 25 c.c. of a saturated solution of boiling ammonium oxalate added, and the boiling continued until the precipi-

[1] Since this procedure does not involve the determination of silica, a second evaporation is unnecessary.

tated calcium oxalate has assumed a well-defined granular form. The precipitate after one hour shall be filtered and washed, then with the filter shall be placed wet in a platinum crucible, and the paper burned off over a small flame of a Bunsen burner; after ignition it shall be redissolved in hydrochloric acid and the solution diluted to 100 c.c. Ammonia shall be added in slight excess, and the liquid boiled. The lime shall then be reprecipitated by ammonium oxalate, allowed to stand until settled, filtered and washed. The combined filtrates from the calcium precipitates shall be acidified with hydrochloric acid, concentrated on the steam bath to about 150 c.c., and made slightly alkaline with ammonium hydroxide, boiled and filtered (to remove a little aluminum and iron and perhaps calcium). When cool, 10 c.c. of saturated solution of sodium-ammonium-hydrogen phosphate shall be added with constant stirring. When the crystallin ammonium-magnesium orthophosphate has formed, ammonia shall be added in moderate excess. The solution shall be set aside for several hours in a cool place, filtered and washed with water containing 2.5 per cent. of NH_3. The precipitate shall be dissolved in a small quantity of hot hydrochloric acid, the solution diluted to about 100 c.c., 1 c.c. of a saturated solution of sodium-ammonium-hydrogen phosphate added, and ammonia drop by drop, with constant stirring, until the precipitate is again formed as described and the ammonia is in moderate excess. The precipitate shall then be allowed to stand about two hours, filtered and washed as before. The paper and contents shall be placed in a weighed platinum crucible, the paper slowly charred, and the resulting carbon carefully burned off. The precipitate shall then be ignited to constant weight over a Meker burner, or a blast not

strong enough to soften or melt the pyrophosphate. The weight of magnesium pyrophosphate obtained multiplied by 72.5 gives the percentage of magnesia. The precipitate so obtained always contains some calcium and usually small quantities of iron aluminum, and manganese as phosphates.

27. A permissible variation of 0.4 will be allowed, and all results in excess of the specified limit but within this permissible variation shall be reported as 5.00 per cent.

VIII. Determination of Specific Gravity[1]

28. The determination of specific gravity shall be made with a standardized Le Chatelier apparatus which conforms to the requirements illustrated in Fig. 1.[2] This apparatus is standardized by the United States Bureau of Standards. Kerosene free from water, or benzine not lighter than 62° Baumé, shall be used in making this determination.

29. The flask shall be filled with either of these liquids to a point on the stem between zero and 1 c.c., and 64 g. of cement, of the same temperature as the liquid, shall be slowly introduced, taking care that the cement does not adhere to the inside of the flask above the liquid and to free the cement from air by rolling the flask in an inclined position. After all the cement is introduced, the level of the liquid will rise to some division of the graduated neck; the difference between readings is the volume displaced by 64 g. of the cement.

The specific gravity shall then be obtained from the formula

$$\text{Specific gravity} = \frac{\text{Weight of cement (g.)}}{\text{Displaced volume (c.c.)}}$$

[1] No specific gravity requirement is shown in A.S.T.M. Standard Specifications and Tests for Portland Cement. Serial Designation: C-9–26.

[2] American Society for Testing Materials, Standards 1924, page 640.

30. The flask, during the operation, shall be kept immersed in water, in order to avoid variations in the temperature of the liquid in the flask, which shall not exceed 0.5° C. The results of repeated tests should agree within 0.01.

31. The determination of specific gravity shall be made on the cement as received; if it falls below 3.10, a second determination shall be made after igniting the sample as described in Section 20.

IX. Determination of Fineness

Apparatus

32. Wire cloth for standard sieves for cement shall be woven (not twilled) from brass, bronze, or other suitable wire, and mounted without distortion on frames not less than 1½ in. below the top of the frame. The sieve frames shall be circular, approximately 8 in. in diameter, and may be provided with a pan and cover.

33. A standard No. 200 sieve is one having nominally an 0.0029-in. opening and 200 wires per inch standardized by the U. S. Bureau of Standards, and conforming to the following requirements:

The No. 200 sieve should have 200 wires per inch, and the number of wires in any whole inch shall not be outside the limits of 192 to 208. No opening between adjacent parallel wires shall be more than 0.0050 in. in width. The diameter of the wire should be 0.0021 in. and the average diameter shall not be outside the limits 0.0019 to 0.0023. The value of the sieve as determined by sieving tests made in conformity with the standard specification for these tests on a standardized cement which gives a residue of 25 to 20 per cent. on the No. 200 sieve, or on

other similarly graded material, shall not show a variation of more than 1.5 per cent. above or below the standards maintained at the Bureau of Standards.

Method

34. The test shall be made with 50 g. of cement. The sieve shall be thoroughly clean and dry. The cement shall be placed on the No. 200 sieve, with pan and cover attached, if desired, and shall be held in one hand in a slightly inclined position so that the sample will be well distributed over the sieve, at the same time gently striking the side about 150 times per minute against the palm of the other hand on the up stroke. The sieve shall be turned every 25 strokes about one-sixth of a revolution in the same direction. The operation shall continue until not more than 0.05 g. passes through in one minute of continuous sieving. The fineness shall be determined from the weight of the residue on the sieve expressed as a percentage of the weight of the original sample.

35. Mechanical sieving devices may be used, but the cement shall not be rejected if it meets the fineness requirement when tested by the hand method described in Section 34.

X. Mixing Cement Pastes and Mortars

36. The quantity of dry material to be mixed at one time shall not exceed 1000 g. nor be less than 500 g. The proportions of cement or cement and sand shall be stated by weight in grams of the dry materials; the quantity of water shall be expressed in cubic centimeters (1 c.c. of water = 1 g.). The dry materials shall be weighed, placed upon a non-absorbent surface, thoroughly mixed

dry if sand is used, and a crater formed in the center, into which the proper percentage of clean water shall be poured; the material on the outer edge shall be turned into the crater by the aid of a trowel. After an interval of ½ minute for the absorption of the water the operation shall be completed by continuous, vigorous mixing, squeezing and kneading with the hands for at least one minute.[1] During the operation of mixing, the hands should be protected by rubber gloves.

37. The temperature of the room and the mixing water shall be maintained as nearly as practicable at 21°C. (70°F.).

XI. Normal Consistency

38. The Vicat apparatus consists of a frame *A*, Fig. 2, page 642, A.S.T.M. Standards 1924, bearing a movable rod *B*, weighing 300 g., one end *C* being 1 cm. in diameter for a distance of 6 cm., the other having a removable needle *D*, 1 mm. in diameter, 6 cm. long. The rod is reversible, and can be held in any desired position by a screw *E*, and has midway between the ends a mark *F* which moves under a scale (graduated to millimeters) attached to the frame *A*. The paste is held in a conical, hard-rubber ring *G*, 7 cm. in diameter at the base, 4 cm. high, resting on a glass plate *H* about 10 cm. square.

39. In making the determination, 500 g. of cement, with a measured quantity of water, shall be kneaded into

[1] In order to secure uniformity in the results of tests for the time of setting and tensile strength the manner of mixing above described should be carefully followed. At least one minute is necessary to obtain the desired plasticity which is not appreciably affected by continuing the mixing for several minutes. The exact time necessary is dependent upon the personal equation of the operator. The error in mixing should be on the side of over mixing.

a paste, as described in Section 37, and quickly formed into a ball with the hands, completing the operation by tossing it six times from one hand to the other, maintained about 6 in. apart; the ball resting in the palm of one hand shall be pressed into the larger end of the rubber ring held in the other hand, completely filling the ring with paste; the excess at the larger end shall then be removed by a single movement of the palm of the hand; the ring shall then be placed on its larger end on a glass plate and the excess paste at the smaller end sliced off at the top of the ring by a single oblique stroke of a trowel held at a slight angle with the top of the ring.

PERCENTAGE OF WATER FOR STANDARD MORTARS

Percentage of water for neat cement paste of normal consistency	Percentage of water for one cement, three standard Ottawa sand	Percentage of water for neat cement paste of normal consistency	Percentage of water for one cement, three standard Ottawa sand
15	9.0	23	10.3
16	9.2	24	10.5
17	9.3	25	10.7
18	9.5	26	10.8
19	9.7	27	11.0
20	9.8	28	11.2
21	10.0	29	11.3
22	10.2	30	11.5

During these operations care shall be taken not to compress the paste. The paste confined in the ring, resting on the plate, shall be placed under the rod, the larger end of which shall be brought in contact with the surface of the paste; the scale shall be then read, and the rod quickly released. The paste shall be of normal consistency when the rod settles to a point 10 mm. below the

original surface in ½ minute after being released. The apparatus shall be free from all vibrations during the test. Trial pastes shall be made with varying percentages of water until the normal consistency is obtained. The amount of water required shall be expressed in percentage by weight of the dry cement.

40. The consistency of standard mortar shall depend on the amount of water required to produce a paste of normal consistency from the same sample of cement. Having determined the normal consistency of the sample, the consistency of standard mortar made from the same sample shall be as indicated in Table I, the values being in percentage of the combined dry weights of the cement and standard sand.

XII. Determination of Soundness[1]

41. A steam apparatus, which can be maintained at a temperature between 98 and 100°C., or one similar to that shown in Fig. 3, A.S.T.M. Standards 1924, p. 644 is recommended. The capacity of this apparatus may be increased by using a rack for holding the pats in a vertical or inclined position.

42. A pat from cement paste of normal consistency about 3 in. in diameter, ½ in. thick at the center, and tapering to a thin edge, shall be made on clean glass plates about 4 in. square, and stored in moist air for 24

[1] Unsoundness is usually manifested by change in volume which causes distortion, cracking, checking or disintegration.

Pats improperly made or exposed to drying may develop what are known as shrinkage cracks within the first 24 hours and are not an indication of unsoundness. These conditions are illustrated in Fig. 4. [See A.S.T.M. Standards 1924, p. 645.]

The failure of the pats to remain on the glass or the cracking of the glass to which the pats are attached does not necessarily indicate unsoundness.

hours. In molding the pat, the cement paste shall first be flattened on the glass and the pat then formed by drawing the trowel from the outer edge toward the center.

43. The pat shall then be placed in an atmosphere of steam at a temperature between 98 and 100°C. upon a suitable support 1 in. above boiling water for 5 hours.

44. Should the pat leave the plate, distortion may be detected best with a straight edge applied to the surface which was in contact with the plate.

XIII. Determination of Time of Setting

45. The following are alternate methods, either of which may be used as ordered:

46. The time of setting shall be determined with the Vicat apparatus described in Section 38.

47. A paste of normal consistency shall be molded in the hard-rubber ring *G* as described in Section 39, and placed under the rod *B*, the smaller end of which shall then be carefully brought in contact with the surface of the paste, and the rod quickly released. The initial set shall be said to have occurred when the needle ceases to pass a point 5 mm. above the glass plate in ½ minute after being released; and the final set, when the needle does not sink visibly into the paste. The test pieces shall be kept in moist air during the test. This may be accomplished by placing them on a rack over water contained in a pan and covered by a damp cloth kept from contact with them by means of a wire screen; or they may be stored in a moist closet. Care shall be taken to keep the needle clean, as the collection of cement on the sides of the needle retards the penetration, while cement on the point may increase the penetration. The time of setting is affected not only by the percentage and temperature of the water used and the amount of knead-

ing the paste receives, but by the temperature and humidity of the air, and its determination is therefore only approximate.

48. The time of setting shall be determined by the Gillmore needles. The Gillmore needles should preferably be mounted as shown in Fig. 5 (*b*).[1]

49. The time of setting shall be determined as follows: A pat of neat cement paste about 3 in. in diameter and $\frac{1}{2}$ in. in thickness with a flat top (Fig. 5 (*a*)),[2] mixed to a normal consistency, shall be kept in moist air at a temperature maintained as nearly as practicable at 21°C. (70°F.). The cement shall be considered to have acquired its initial set when the pat will bear, without appreciable indentation, the Gillmore needle $\frac{1}{12}$ in. in diameter, loaded to weigh $\frac{1}{4}$ lb. The final set has been acquired when the pat will bear without appreciable indentation, the Gillmore needle $\frac{1}{24}$ in. in diameter, loaded to weigh 1 lb. In making the test the needles shall be held in a vertical position, and applied lightly to the surface of the pat.

XIV. Tension Tests

50. The form of test piece shown in Fig. 6[3] shall be used. The molds shall be made of non-corroding metal and have sufficient material in the sides to prevent spreading during molding. Gang molds when used shall be of the type shown in Fig. 7.[4] Molds shall be wiped with an oily cloth before using.

51. The sand to be used shall be natural sand from Ottawa, Ill., screened to pass a No. 20 sieve, and retained

[1] A.S.T.M. Standards 1924, p. 647.
[2] A.S.T.M. Standards 1924, p. 647.
[3] A.S.T.M. Standards 1924, p. 648.
[4] A.S.T.M. Standards 1924, p. 649.

on a No. 30 sieve. This sand may be obtained from the Ottawa Silica Co., Ottawa, Ill.

52. This sand, having passed the No. 20 sieve, shall be considered standard when not more than 5 g. pass the No. 30 sieve after one minute continuous sieving of a 500-g. sample.

53. The sieves shall conform to the following specifications:

The No. 20 sieve shall have between 19.5 and 20.5 wires per whole inch of the warp wires and between 19 and 21 wires per whole inch of the shoot wires. The diameter of the wire should be 0.0165 in. and the average diameter shall not be outside the limits of 0.0160 and 0.0170 in.

The No. 30 sieve shall have between 29.5 and 30.5 wires per whole inch of the warp wires and between 28.5 and 31.5 wires per whole inch of the shoot wires. The diameter of the wire should be 0.0110 in. and the average diameter shall not be outside the limits 0.0105 to 0.0115 in.

54. Immediately after mixing, the standard mortar shall be placed in the molds, pressed in firmly with the thumbs and smoothed off with a trowel without ramming. Additional mortar shall be heaped above the mold and smoothed off with a trowel; the trowel shall be drawn over the mold in such a manner as to exert a moderate pressure on the material. The mold shall then be turned over and the operation of heaping, thumbing and smoothing off repeated.

55. Tests shall be made with any standard machine. The briquettes shall be tested as soon as they are removed from the water. The bearing surfaces of the clips and briquettes shall be free from grains of sand or

dirt. The briquettes shall be carefully centered and the load applied continuously at the rate of 600 lb. per minute.

56. Testing machines should be frequently calibrated in order to determine their accuracy.

57. Briquettes that are manifestly faulty, or which give strengths differing more than 15 per cent. from the average value of all test pieces made from the same sample and broken at the same period, shall not be considered in determining the tensile strength.

XV. Storage of Test Pieces

58. The moist closet may consist of a soapstone, slate or concrete box, or a wooden box lined with metal. If a wooden box is used, the interior should be covered with felt or broad wicking kept wet. The bottom of the moist closet should be covered with water. The interior of the closet should be provided with non-absorbent shelves on which to place the test pieces, the shelves being so arranged that they may be withdrawn readily.

59. Unless otherwise specified all test pieces, immediately after molding, shall be placed in the moist closet for from 20 to 24 hours.

60. The briquettes shall be kept in molds on glass plates in the moist closet for at least 20 hours. After from 20 to 24 hours in moist air the briquettes shall be immersed in clean water in storage tanks of non-corroding material.

61. The air and water shall be maintained as nearly as practicable at a temperature of 21°C. (70°F.).

Experiment D-7

Strength of Cement Mortars in Compression

This experiment will give the quality of a cement as shown by compression tests of standard Ottawa sand mortars.

References.—Proc. Amer. Soc. for Testing Materials, 1919, Part I.

Hool and Johnson Handbook, page 10.

Mills Material of Construction, Art. 85.

Material: Any brand of cement.

Special Apparatus: At least six cylindrical molds, 2 in. in diameter and 4 in. in height. Standard metal tamper 1 in. in diameter and ¾ lb. in weight.

Procedure.—Using standard Ottawa sand mix a 1 to 3 mortar of Normal Consistency. (See Table, p. 86).

Note.—If sufficient mortar for six 2 by 4-in. cylinders is to be mixed in a single batch, 750 g. of cement and 2250 g. of standard sand will be required. In this case the mixing shall be continued for 1½ minutes. (See standard methods of mixing and molding, page 84.) Place the empty mold on an oiled glass plate and fill with the mortar in layers of 1 in. tamping each layer with the standard metal tamper. The top should be carefully finished by heaping up the mortar and smoothing off with the trowel. An oiled glass cover plate should be placed on top and remain until molds are removed (after 1 day storage in moist air).

Test the specimens at the end of 6 and 27 days' storage in water. The testing machine should be capable of applying the load continuously and uniformly to failure. The moving head of the testing machine shall travel at the rate of not less than 0.05 or more than 0.10 in.

per minute. During the test, a spherical bearing block, accurately centered, shall be used on top of the cylinder.

Report: Follow the standard form on page 7.

TABLE ON UNIT STRESSES FOR LOADS ON 2-IN. CYLINDERS (3.14 SQ. IN.)

Total load.....	.....	10	20	30	40	50	60	70	80	90
Unit stress.....	.....	3	6	10	13	16	19	22	25	29
Total load (lb.).	000	100	200	300	400	500	600	700	800	900
0000	.....	32	64	95	127	159	191	223	255	286
1000	318	350	382	413	445	477	509	541	573	604
2000	637	669	701	732	764	796	828	860	892	923
3000	955	987	1019	1050	1082	1114	1146	1178	1210	1241
4000	1273	1305	1337	1368	1400	1432	1464	1496	1528	1559
5000	1592	1624	1656	1687	1719	1751	1783	1815	1847	1878
6000	1910	1942	1974	2005	2037	2069	2101	2133	2165	2196
7000	2228	2260	2292	2323	2355	2387	2419	2451	2483	2514
8000	2546	2578	2610	2641	2673	2705	2737	2769	2801	2832
9000	2865	2897	2929	2960	2992	3024	3056	3088	3120	3151

Article 5

STUDY OF AGGREGATES

Notes on the Sampling of Aggregates Used in Concrete Construction.[1]—The value of tests of the constituent materials entering into a concrete construction depend almost entirely upon whether the samples obtained are thoroughly representative of the aggregates used.

When it is positively certain that the material sampled is the material shipped and used in the construction then the samples may be taken at the pit or quarry. When there is uncertainty as to this point, samples for test

[1] See Year Book A.S.T.M. 1924, page 933, for additional methods.

should be taken from shipments as they arrive where they are to be used.

Sampling of Stone from Ledges or Quarries for Quality

Inspect ledge or quarry face closely to determine any variation in different layers. Observe any difference in color or structure, and if necessary to secure unweathered specimens, break pieces from different layers.

For standard stone test take separate samples of at least 30 lb. each of fresh unweathered specimens from all layers that appear to vary in color or structure. When more than one piece is taken, the minimum size shall be 2 in., except that there shall be one piece of a minimum size of 4 in. $\times$ 5 in. $\times$ 3 in. on which the bedding plane is marked. This latter piece shall be free from seams or fractures as it is used in the toughness or compression test.

The size of sample for concrete test will have to have special instruction as it depends on the kind of tests to be made and the number of specimens necessary.

Sampling of Gravel or Sand

Sampling at a pit which has exposed vertical faces may be done by scooping out a small uniform vertical channel from bottom to top of faces. If the material excavated from this channel is more than desired it may be reduced by the method of quartering. Samples taken in this way from the various faces of a pit should be kept separate with the proper identification as to location, inasmuch as it may happen that some parts of the same bank may yield an undesirable material.

The pit should be carefully examined before selecting

the location of a sample. It frequently happens that a bank is not of a homogeneous mixture throughout and that layers or pockets are found in which is a material of uniform size or perhaps of clay. Boulders may be present in one section and not in another. If the pit is a large one more than one sample must be taken to properly represent the deposit.[1]

Deposits that have no open face shall be sampled by means of test pits. The number and depth of these will depend on local conditions and the amount of material to be used from the source.

Sampling the aggregate after it has arrived on the job may be done by collecting and mixing a small quantity from many different parts of the pile, or bin. These small quantities should be obtained by digging into the pile not by collecting what rolls down the outside as that is likely to be composed of only the coarser particles. The test samples themselves should always be acquired from the larger samples by the method of quartering.

Quartering.—To quarter a sample of aggregate it is spread out on a clean flat surface in the form of a circular disc of uniform thickness. Care should be taken that particles of different size are distributed through the mass. The material is then divided into four quarters and two opposite quarters removed completely. The remaining quarters are then mixed together and the operation repeated. This is done until the quantity remaining is the size required for the experiment.

Shipping and Storing of Samples.—The samples should be shipped and stored in such a way as to retain as much as possible of the natural moisture of the material.

[1] Samples of run of bank should consist of at least 100 lb. of material where the gravel content is 50 per cent. or more of the whole.

Experiment E-2

Test of Sand for Cleanness

References.—See Year Book A.S.T.M. 1924. Pps. 766 and 932.

Comment.—The impurities in sand are: (1) *Silt*, the fine scum that settles on sand that has been shaken in water. Silt may contain organic matter, such as loam, sugar, sewage, that may prevent concrete from hardening. (2) *Clay*, an inorganic, fine material that may assist in filling up the pores in a clean concrete. Fine soluble limestone dust is especially objectionable.

A dirty sand will stain the palm of the hand, but specific tests should be made:

1. *Method of Washing.*—Dry a 220 gram sample obtained by quartering and at room temperature to avoid baking the clay. Extra care must be taken in dividing the material after drying to prevent separation of fine from coarse. Weigh 200 grams on the 100 sieve, soak in water to soften any lumps; wash on the sieve in a gentle stream of water; dry under a gas burner, and reweigh. Per cent. of silt is loss in weight divided by 200 and multiplied by 100.

2. *Method of Decantation or Elutriation* (*for field use*). Place 20 c.c. of sand, obtained by quartering, in a 100 c.c. cylinder with 30 c.c. of lukewarm water. Stir with a wire for 30 seconds; allow to settle for 30 seconds. Decant water in a second 100 c.c. cylinder. Stir up sand in 1st cylinder with fresh portion of water, and repeat process 3 times. Settle the two cylinders for 1 hour. Note silt in cylinder No. 2 and sand in Cylinder No. 1.

$$\text{Per cent. of Silt} = \frac{\text{Number of c.c.in Cyl. No. 2}}{\text{c.c. of silt in Cyl. No. 2} + \text{c.c. of sand in No. 1}} \times 100.$$

A more accurate expression is perhaps obtained by dividing amount of silt by original volume of sand.

NOTE.—A rough method is to stir up sand in Cyl. No. 1 and allow silt to settle on top. Measure height of sand and of silt on top.

NOTE.—The per cent. of silt by volume is from one to two times the per cent. by weight.

3. *Silt Determination of Road Sands and Gravel.*

STANDARD TEST, AMER. SOC. FOR TESTING MATERIALS YEAR BOOK 1924. PP. 932.

1. **Scope.**—This test covers the determination of the quantity of clay and silt in natural sands and gravel to be used in highway construction.

2. **Treatment of Sample.**—The sample as received shall be moistened and thoroughly mixed, then dried to constant weight at a temperature between 100 and 110°C. (212 and 230°F.)

3. **Method.**—A representative portion of the dry material, weighing 500 g. for sand and not less than 50 times the weight of the largest stone in the sample for gravel shall be selected from the sample, and placed in a dried and accurately weighed pan or vessel. The pan shall be 12 in. (30.2 cm.) in diameter by not less than 4 in. (10.2 cm.) deep, as nearly as may be obtained. Pour sufficient water in the pan to cover the gravel and agitate vigorously for 15 seconds, using a trowel or stirring rod. Allow to settle for 15 seconds, and then pour off the water into a tared evaporating dish, taking care not to pour off any gravel. Repeat until the wash water is clear. Dry the washed material to constant weight in an oven at a temperature between 100 and 110°C. (212 and 230°F.), weigh, and determine the net weight of gravel.

The percentage of clay and silt shall be calculated from the formula:

$$\text{Percentage of Clay and Silt} = \frac{\text{Original weight} - \text{weight after washing}}{\text{Original weight}} \times 100.$$

For a check on the results, evaporate the wash water to dryness and weigh the residue:

$$\text{Percentage of Clay and Silt} = \frac{\text{Weight of residue}}{\text{Original weight}} \times 100.$$

4. *Test for Organic Matter.*—Organic matter in the silt is determined by the Colorimetric Test. A.S.T.M. Year Book 1924. Pp. 766.

Fill a 12 oz. prescription bottle to the 4½ oz. mark with the sand to be tested, then add 3 per cent. solution of sodium hydroxide until the bottle is filled to the 7 oz. mark. Allow mixture to stand over night and then examine color of liquid above sand. A very dark orange is objectionable, a dark brown or black color indicates that the sand is badly contaminated, while a white or light yellow color indicates that there is little organic impurity present.

NOTE.—Proportionate amounts may be used and the test made in *any* clear glass container.

Experiment E-3

WEIGHT OF AGGREGATES

The weight per cubic foot gives a close estimate of the value of sand or other aggregate

Some general considerations must be understood in this experiment.

Sizing.—The weight per cubic foot of sand or of pebbles of graded sizes would be greater than if of uniform

size. Why? Likewise the weight per cubic foot of the mixture of the fine and coarse aggregate will be greater than of either alone.

The volume produced by mixing a cubic foot of coarse aggregate with a cubic foot of fine aggregate will be less than 2 cu. ft., about $1\frac{3}{4}$.

Moisture.—A film of water forces sand particles apart. Therefore dry sand swells when damp and weighs less per cubic foot. The amount of the swelling depends

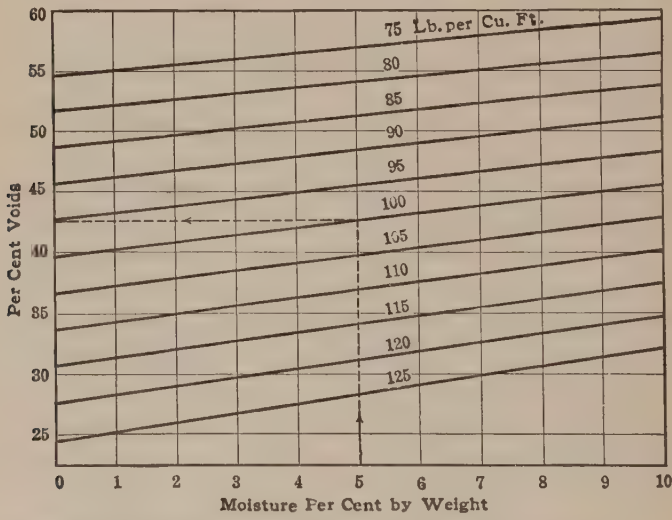


FIG. 28.—Voids in sand and gravel when moisture and unit weight are known.

upon—(*a*) the amount of water; and (*b*) the fineness of the sand. The maximum bulking effect in sand occurs at a per cent. of water from 5 to 6 per cent. by weight, and is 30 per cent. for fine sand, 25 per cent. for medium sand, and 20 per cent. for coarse sand. Pebbles are only slightly affected 1 per cent. of water may increase

the volume of fine sand 10 to 15 per cent. As the amount of water increases, filling the voids, a flood stage is reached and the sand return to its former dry volume. For Example—Coarse Sand: dry, 107½ lb. per cu. ft.; wet, with 3 per cent. of water, 94 lb. per cu. ft. Medium Sand: dry, 99½ lb. per cu. ft.; wet with 5 per cent. of water, 90 lb. per cu. ft. Above cases are for compacted sand. When sand that has been in a rain storm is re-shoveled in a loose pile, the increase in volume may be ½ to ⅓ more.

Evidently the test for weight per cubic foot must be standard as to moisture and compacting.

Determine the Weight per Cubic Foot by Standard Rod Method

The Rod method is operated as follows:

Fill the measure one-third full of the aggregate, then, with a pointed iron rod of a prescribed size, jab or puddle the aggregate twenty-five times, distributing the strokes over the surface of the aggregate and avoiding penetrating through the layer of aggregate so as to hit the bottom of the measure. Then add another one-third to the contents of the measure and again jab with the iron rod twenty-five times, penetrating only the last layer of aggregate placed in the measure. Next, fill the measure to overflowing and repeat the jabbing, then strike off the surplus sand with the iron rod and weigh.

Standard Method of Test for Unit Weight of Aggregates, Year Book 1924. Pp. 759 (in Part)

Measures.—The measure shall be of metal, preferably machined to accurate dimensions on the inside, cylindrical in form, watertight, and of sufficient rigidity to

retain its form under rough usage, with top and bottom true and even, and preferably provided with handles.

The measure shall be of $\frac{1}{10}$, $\frac{1}{2}$ or 1 cu. ft. capacity, depending on the maximum diameter of the coarsest particles in the aggregate, and shall be of the following dimensions:

Capacity, cu. ft.	Inside diameter, in.	Inside height, in.	Minimum thickness of metal, U.S. gage	Diameter of largest particles of aggregate, in.
$\frac{1}{10}$	6.00	6.10	No. 11	Under $\frac{1}{2}$
$\frac{1}{2}$	10.00	11.00	No. 8	Under $1\frac{1}{2}$
1	14.00	11.23	No. 5	Over $1\frac{1}{2}$

Tamping Rod.—The tamping rod shall be a straight metal rod $\frac{3}{4}$ in. in diameter and 18 in. long, with one end tapered for a distance of 1 in. to a blunt bullet-shape point.

Report the weight per cubic foot of the several sands provided by Instructor to include:

Medium Sand: (*a*) dry, (*b*) with 5 per cent. water; Ottawa Sand; Mixed fine and coarse gravel aggregate; bank run gravel; crushed stone.

If the specific gravity and voids of these have been determined by previous experiments, report the extent to which these weights are a measure of the voids.

Problems.—The Air Dry Sand, (*a*) is bought by the ton to be used in a 1–2–4 concrete proportioned by volume. It becomes damp through exposure as in (*b*). Report the additional amount of sand (*b*) that should be used in mixing the concrete.

Freight charges are paid for sand by the ton. What would be the proportionate amounts of freight charges

on a car load of sand (*a*) dry and (*b*) damp with 5 per cent. water.

Experiment E-4

The Specific Gravity of Various Materials Used as an Aggregate in Concrete

Object.—The object of this test is to determine the specific gravity of the various materials used as an aggregate in concrete.

Materials.—The following materials will be used: sand or gravel, stone. A porous material should first be moistened to fill the pores and the surfaces of the part ticles be dried by means of blotting paper. A correction for the weight of absorbed moisture can be made by drying the material in an oven.

American Society for Testing Materials Standard Tests are as follows: See Year Book 1924. Pp. 926 and 928.

1. *Fine Aggregates.*

(*a*) Le Chatelier Test using approx. 64 g. of material as in test for cement except that liquid may be water or kerosene.

(*b*) Jackson Test using about 50 g. of material in the following apparatus:

The determination shall be made with a Jackson specific gravity apparatus, which shall consist of a burette, with graduations reading to 0.01 in specific gravity, about 23 cm. (9 in.) long and with an inside diameter of about 0.6 cm. (0.25 in.), which shall be connected with a glass bulb approximately 13 cm. (5.5 in.) long and 4.5 cm. (1.75 in.) in diameter, the glass bulb being of such size that from a mark on the neck at the top to a mark on the burette just below the bulb, the capacity is exactly 180 c.c. (6.09 liquid oz.); and an

Erlenmeyer flask, which shall contain a hollow ground-glass stopper having the neck of the same bore as the burette, and shall have a capacity of exactly 200 c.c. (6.76 oz.) up to the graduation on the neck of the stopper.

2. *Coarse Aggregates.*—The apparent specific gravity shall be determined in the following manner:

1. The sample, weighing 1000 g. and composed of pieces approximately cubical or spherical in shape and retained on a screen having 1.27-cm. (½-in.) circular openings, shall be dried to constant weight at a temperature between 100 and 110°C. (212 and 230°F.), cooled, and weighed to the nearest 0.5 g. Record this weight as weight *A*. In the case of homogeneous material, the smallest particles in the sample may be retained on a screen having 1¼-in. circular openings.

2. Immerse the sample in water for 24 hours, surface-dry individual pieces with aid of a towel or blotting paper, and weigh. Record this weight as weight *B*.

3. Place the sample in a wire basket of approximately ¼-in. mesh, and about 12.7 cm. (5 in.) square and 10.3 cm. (4 in.) deep, suspend in water[1] from center of scale pan, and weigh. Record the difference between this weight and the weight of the empty basket suspended in water as weight *C*. (Weight of saturated sample immersed in water.)

4. The apparent specific gravity shall be calculated by dividing the weight of the dry sample (*A*) by the difference between the weights of the saturated sample in air (*B*) and in water (*C*), as follows:

$$\text{Apparent Specific Gravity} = \frac{A}{B - C}.$$

[1] The basket may be conveniently suspended by means of a fine wire hung from a hook shaped in the form of a question mark with the top resting on the center of the scale pan.

5. Attention is called to the distinction between apparent specific gravity and true specific gravity. Apparent specific gravity includes the voids in the specimen and is therefore always less than or equal to, but never greater than the true specific gravity of the material.

Approximate Method.—Weigh graduate and fill half full of water and weigh again, being careful to see that weight of water and volume check. Add an equal volume of the dry aggregate after weighing, and note exact rise of the water level. Let W = weight of material, and G weight of water displaced. Then specific gravity of the material $= S = \frac{W}{G}$ if metric units are employed.

Report should be in standard form.

Experiment E-5

Determination of Voids in Aggregates

References.—Johnson's Materials of Construction, 6th Ed. p. 409, 417.

Taylor & Thompson, 5th Ed. p. 181.

Hool & Johnson, pages 25, 26, 27.

The voids in an aggregate are the interstices between the particles.

The total volume of hollow spaces constitute the absolute voids. The total volume of hollow spaces minus volume occupied by moisture constitute the air filled voids.

Note:—The absolute volume is the total solid mass in a cubic unit. The absolute volume of the aggregate and of the cement plus the water and air voids must equal unity.

Material.—Any aggregate usually sand, gravel or broken stone, thoroughly dried.

Special Apparatus.—For coarse materials: Use a vessel which is water tight and capacity is at least ½ cu. ft. Volume of water may be determined by weighing.

For finer materials: Use a 1000 c.c. graduate or 500 c.c. graduate if very fine materials are being measured. Volume of water may be either measured or weighed.

Determination of Voids by Specific Gravity Method. See Year Book A.S.T.M. 1924. Pp. 761.

In this method the apparent specific gravity must be known or be determined as in Experiment E-4.

Knowing the specific gravity of the aggregate, the weight of a cubic foot of the solid material may be determined.

Then determine the weight of a known volume of the aggregate usually in pounds per cubic foot as determined in Experiment E-3 in the state in which the percentage of voids is required, that is, loose, shaken or packed. From these weights the percentage of voids may be figured.

Experiment E-6

Volume—Moisture Relation of Sands

References.—Taylor & Thompson.

Proc. of A.S.T.M., 1920.

Manual.

Materials.—Dry sand.

Apparatus.—Standard circular measure, 20 c.c. graduate, one ⅝″ pointed rod, large trowel, mixing pan.

Procedure.—Weigh out 35 pounds of sand. Determine moisture of the apparently dry sand. (1000 gram sample is sufficient for this determination.) Determine the weight per cubic foot of the dry sand by the Rod Method (See Manual, page 101). Add 1 per cent. water

to the original 35 pounds of dry sand and determine the weight per cubic foot. Determine the weight per cubic foot for every per cent. of moisture up to 8 per cent. Each member of the party should make a test for weight per cubic foot for each condition of moisture.

Report.—A concise report is desired.

NOTE.—The increase in volume is calculated on a basis of the sand at zero per cent. moisture by two methods; 1st, when the water added is taken into account and 2nd, when the water added it not taken into account.

1st Method.—"Knowing the weight per cubic foot of the sand both dry and moist, the percentage of increase in volume due to the added moisture is calculated from:

$$P = \frac{W_1(1 + r) - W_2}{W_2} \times 100$$

where P = per cent. increase in volume, r = ratio of water added to weight of dry material, W_1 weight per cubic foot of dry material, and W_2 = weight per cubic foot of moist material.

2nd Method.—Calculated from:

$$P = \frac{W_1 - W_2}{W_2} \times 100$$

where W_1 and W_2 have the same meaning as above.

Curves should be plotted showing weight per cubic foot, and increase in volume (by both methods), as ordinate, against the per cent. moisture as abscissae.

Experiment E-7

STUDY OF SIEVES

The results of sieving tests will not be comparable and specifications cannot be applied properly unless the standard sieves present the same spacing and diameter of wires. The commercial numbers designating the

sieves are approximately the number of meshes per linear inch. There are two standard series in use at the present time.

I. *Tyler Series*—EACH OPENING DOUBLE THE NEXT LOWER

No. or size	Size of clear opening, in.	Diameter of wire, in.
200	0.0029	0.0021
100	0.0058	0 0042
48	0.0116	0.0092
28	0.0232	0.0125
14	0.0460	0.0250
8	0.0930	0.0320
4	0.1850	0.0650
⅜	0.3700	0.0920
¾	0.7500	0.1350
1½	1.5000	

II. *The A.S.T.M. Standards*—1924. PP. 850 E-11-25-T

No. or size	Size of clear opening, in.	Diameter of wire, in.
100	0.0059	0.0040
80	0.0070	0.0047
50	0.0117	0.0074
40	0.0165	0.0098
30	0.0232	0.0130
20	0.0331	0.0165
10	0.0787	0.0299

In sieving observe the following directions:

Aggregate should be dry.

Use 100, 250, 500, or 1000 grams of the sample since the results are then more easily turned into per cents.

The samples to be tested and placed on the coarsest sieve, which is the top one in the nest. The sieving is

complete when not more than 1 per cent. passes after one minute shaking.

The results are plotted in a curve showing the per cents. retained in the various sieves. The most convenient diagram is on the logarithmic scale.

Sieve Analysis of Aggregates.—A well graded aggregate contains particles of different sizes. Specifications prescribe the amounts of the various sizes of aggregates entering into a desired concrete.

Experiment E-8

Sieve Analysis of Aggregates

The experiment gives graphically the graduations of sizes in an aggregate and by comparisons with a theoretical ideal aggregate the improvement of the aggregate may be known.

Proc. Amer. Concrete Institute, 1917 pages 432 and 440.

Report of Joint Comm. 1924.

Concrete Eng'rs Handbook, Hool and Johnson, page 23.

Standards of A.S.T.M., C 41–24.

Material.—Gravel and sand or broken stone with screenings, or stone and sand well dried.

1. A representative test sample of the aggregate shall be selected by quartering or by use of a sampler, which after drying will give not less than the following:

(*a*) Fine aggregate, 500 g.

(*b*) Coarse aggregate or a mixture of fine and coarse aggregates, weight in grams, 3000 times size of largest sieve required, measured in inches.

The coarser the aggregate, the larger should be the size of the original sample. The sample should be separated

into its sizes by sieving, beginning with the largest sieves. The amount remaining on each sieve after five minutes, shaking should be weighed, also the amount passing the finest sieve. If the sum of these is not equal to the original weight, distribute the error proportionately.

TABLE I.

Sieve number[1] or size in inches	Sieve opening		Wire diameter		Tolerance, per cent.			
	mm.	in.	mm.	in.	average	Wire diameter		Maximum opening
						Under	Over	
No. 100	0.149	0.0059	0.102	0.0040	6	15	35	40
No. 50	0.297	0.0117	0.188	0.0074	6	15	35	40
No. 30	0.59	0.0232	0.33	0.0130	5	15	30	25
No. 16	1.19	0.0469	0.54	0.0213	3	15	30	10
No. 8	2.38	0.0937	0.84	0.0331	3	15	30	10
No. 4	4.76	0.187	1.27	0.050	3	15	30	10
⅜-in.	9.5	0.375	2.33	0.092	3	10	10	10
¾-in.	19.0	0.75	3.42	0.135	3	10	10	10
1-in.	25.4	1.00	4.12	0.162	3	10	10	10
1½-in.	38.0	1.50	4.50	0.177	3	10	10	10
2-in.	50.8	2.00	4.88	0.192	3	10	10	10
3-in.	76.0	3.00	6.3	0.25	3	10	10	10

[1] The requirements for sieves No. 100 to No. 4 conform to the requirements of the U. S. Standard Sieve Series as given in U. S. Bureau of Standards *Letter Circular No.* 74. The liberal tolerances will permit the use of certain sieves which do not exactly correspond to the numbers given in table.

Note the actual size of the largest particle in the sample.

Computations.—Plot a diagram with per cents. passing the sieve as ordinates and size of mesh of the different sieve as abscissæ.

Plot also on this diagram, curves representing the specifications in Appendix II.

Discussion of Results.—In what sizes of particles is the aggregate deficient? How may this be remedied in a practical way?

If the aggregate should be screened into two or more parts and these recombined in new proportions, indicate

on what sieves to screen, and the new proportions of each size to use.

Give the proportions for an assumed concrete.

INFORMATION

Yield of Concrete and Quantities Required

The volume of mixed concrete is approximately two-thirds of the total volume of the separate cement, sand and coarse aggregate. The volumetric shrinkage of sand and gravel when mixed together is about 10 to 20 per cent. These are rough approximates. The actual shrinkage will depend upon the character and sizing of the aggregate, consistency, richness of mix, etc.

Fuller's Rule.—Fuller's rule is a simple approximate rule advanced by W. B. Fuller as follows:

Barrels of cement per cubic yard of concrete = $\frac{10.5}{C+S+G}$

Number of cubic yards of sand = $\frac{1.55}{C+S+G} \times S$

Number of cubic yards of coarse aggregate = $\frac{1.55}{C+S+G} \times G$

Where C = number of parts of Cement.
S = number of parts of Sand.
G = number of parts of Coarse Aggregate.

Thus for a 1:2:4 mix—

$$\text{Bbls. of Cement} = \frac{10.5}{1+2+4} = \frac{10.5}{7} = 1.50$$

$$\text{Cubic Yards of Sand} = \frac{1.55}{7} \times 2 = 0.45$$

This rule is approximate. The sizing of the different aggregates is not considered.

Approximate amounts of Materials required for 1 cu. yd. of concrete.

Proportion	Cement, bbl.	Sand, cu. yd.	Gravel or stone, cu. yd.
1:2:4	1.50	0.45	0.89
1:2½:5	1.24	0.46	0.92
1:3:6	1.05	0.47	0.93
1:4:8	0.81	0.48	0.96

On account of settlement of stone in transit, from 8 to 12 per cent., it is usual to order it by the ton. Weight of broken stone at the crusher is: for limestone, 2300–2600 lb. per yd.; for trap 2400–2700 lb. per yd.

Extensive tables will be found in "Concrete, Plain and Reinforced" by Taylor and Thompson, pages 213 to 217.

Caution.—The Aberthaw Construction Company remarks that on account of waste on the job, the direct use of these tables will result in a shortage of material. The Company estimates the same amount of sand and coarse aggregate for 1:2:4 concrete as for 1:2:2, varying only the cement. Thus for 1 yd. of concrete.

Proportion	Cement, bbl.	Sand, cu. yd.	Stone, tons
1:2½:5	1.36	0.50	1.30
1:2:4	1.66	0.50	1.30
1:1½:3	2.00	0.50	1.30
1:1:2	2.86	0.50	1.30

1.3 tons of broken limestone is approximately 1 yd.

Experiment E-9

Hand Mixing of Concrete

Hand-mixed concrete is not under so good a control as machine-mixed concrete and, therefore, not so uniform. The student should learn the appearance and behavior of well mixed concrete with respect to consistency, uniformity, harshness, etc.

The following directions from the Manual of the American Railway Engineering Association should be carried out. First, however, determine in advance the amount of material needed and the proper consistency. (See Exper. No. E-11, E-16, E-17 or F-2.)

"When it is necessary to mix by hand, the mixing shall be on a watertight platform of sufficient size to accommodate men and materials for the progressive and rapid mixing of at least two batches of concrete at the same time. Batches shall not exceed ½ cu. yd. each. The mixing shall be done as follows; the fine aggregates shall be spread evenly upon the platform, then the cement upon the fine aggregates, and these mixed thoroughly until of an even color. The water necessary to mix a thin mortar shall then be added and the mortar spread again. The coarse aggregates, which, if dry, shall first be thoroughly wetted, shall then be added to the mortar. The mass shall then be turned with shovels or hoes until thoroughly mixed and all the aggregates covered with mortar. Or, at the option of the Engineer, the coarse aggregates may be added before, instead of after, adding the water."

Notice that a concrete that appears dry at first will become easily flowing after longer mixing. If the concrete works harsh and the aggregate tends to separate, more cement or more fine sand is needed.

Note.—(1) Does free water appears when the mass is struck with a shovel. (2) At what angle with the horizontal will the concrete flow off the shovel. (3)

If the concrete will hold a level surface in a wheelbarrow while the aggregate does not sink below the surface. (4) If the concrete quakes while it is being tamped to position.

See that the tools are cleaned after use.

A convenient method for mixing concrete by one man is as follows:

The materials are mixed dry in a mortar box with high sides and a sloping end. With the hoe draw the dry materials toward the sloping end and supply water as needed, mixing a small batch of concrete thoroughly. When the batch has been used, another small batch is mixed in the same manner.

Experiment E-10

Mixing Concrete by Machine Mixer

References.—Johnson's Materials of Construction, 5th Ed. pp. 439–441.

American Concrete Institute Proceedings.

Final Report of Joint Committee, Proc. A.S.T.M., 1917, p. 219.

Obtain catalogue of type of mixer under operation and study design and operation of the machine. Check the following: *Type:* batch; continuous; *Discharge:* tilting, spout. *Loading:* state method. *Shape of Drum, Arrangement of Interior Blades. Control. Speed of Drum Recommended. Movement of Concrete in Mixer. Measurement of Water. Time. Condition of Blades. Cleanness of Interior.*

Observe action of mixer and report following:

Time Required to Discharge. Does Mixer Scatter Concrete in Discharging? Proportion of Drum Capacity filled with Concrete, Time of Mixing. Water, Gallon per Bag of Cement. Uniformity of Mixing. What is the

remedy when the mix separates or works too harsh? *Output of mixer in cubic yards per hour.*

In mixing with batch machines, it is desirable to mix the water, cement and aggregate in the order named. Good concrete can be produced in 1 to 1½ minutes of time of mixing. For machines of two or more cubic yards capacity the minimum time of mixing should be two minutes. The speed of rotation should be approx. 16 r.p.m. A speed at the periphery of the drum of about 200 ft. per minute is a general average for different types of mixers.

Experiment E-11

Amount of Water Required for Mixing

Cement and water form a paste that binds the aggregate together and lubricates the aggregate to permit thorough mixing. An excess of water unduly dilutes and weakens the cement paste. Therefore, the minimum amount of water should be used that will give the required workability, mobility, or consistency to the concrete. This consistency is kept constant on any one job but varies with the job. A thin wall with steel reinforcements requires a wet concrete; concrete road, a medium concrete; sidewalk base, a dry concrete.

The richer the mix, the more water required (22 per cent. by weight) to hydrate the cement. The amount of water in concrete is best expressed as the volume of water in relation to the volume of cement. A volume, ratio of 0.8, is 0.8 cu. ft. of water to 1 cu. ft. of packed cement, *i.e.*, nearly 6.4 gal. per bag of cement.

The ultimate strength of the concrete upon which unit stresses are to be based, shall be assured, in the absence of tests specified in Paragraph 6 to be as follows:

Approximate mix volume of Portland cement to sum of separate volumes of fine and coarse aggregate	Water-ratio* U. S. gal. per 94-lb. sack of cement	Assumed ultimate strength at 28 days lb. per sq. in.
Plastic Mass Concrete (Slump 1 to 3 in.)		
1–6	7¼	2000
1–5	6¼	2500
1–4	5¼	3000
Moderately Wet Concrete (Slump 6 to 8 in.)		
1–6	8	1600
1–5	7¼	2000
1–4¼	6½	2500
1–3½	5¼	3000
Very Wet Concrete (Slump 10 in. or more)†		
1–5	8	1600
1–4	7¼	2000
1–3¼	6½	2500
1–2½	5¼	3000

* Water or moisture contained in the aggregate must be included in computing the water-ratio.

† Concrete of this consistency, while frequently used, should be avoided, as it will be porous and of low resistance to weathering.

The water absorbed in a porous aggregate, and the moisture in an aggregate that has been exposed to the weather, must be added to or subtracted from the above table.

The finer the aggregate the more water is required to wet the surface of the particles. For instance, fine sand requires more water than coarse sand and, therefore, the cement must be increased if the same strength of paste is expected.

Methods of Measuring Consistency

Such methods are not well standardized.

Experiment.—Determine the amount of water required to bring about a consistency, described below, of a 1–2–3 mix, using a local aggregate from the field.

Consistency.—The consistency of the concrete shall be such that when a cylinder 6 in. in diameter and 12 in. in length is filled with concrete and tamped until all voids are filled and a slight film of mortar appears on the surface and the cylinder then removed, the vertical settlement or "slump" of the concrete shall not exceed 2 in. when a mechanical finishing machine is used, nor more than 4 in. when the finishing is done by other methods permitted in these specifications.[1]

Consistency is usually judged by the general behavior of the concrete but sometimes tests are specified.

Description of Slump Tests.—(*a*) By the "Cylinder Slump" Test development of Abrams, which is thus performed.

Mix the concrete thoroughly, adding the estimated amount of water.

Tamp the concrete into a galvanized iron mold which is a cylinder 6 in. in diameter and 12 in. high. The cylinder is filled in two layers. Each layer is tamped for 40 strokes with a $\frac{5}{8}$ in. round steel rod.

Then draw the mold up, off the specimen, and note how much the specimen shortens or slumps in height. The consistency is expressed by the slump. Consistency = 1.0, slump is $\frac{1}{2}$ to 1 in. Consistency = 1.10, slump is 5 to 6 in. Consistency = 1.25, slump is 8 to 10 in.

This test applies to sands and gravels rather than

[1] Extract from specifications for concrete used in roads.

to sand and broken stone. It is more reliable for wet mixes.

(*b*) *The Roman Cone Test for Consistency.*[1] In place of the cylinder a truncated cone is used, 8 in. diameter of base, 4 in. diameter of top and 12 in. high. The mold shall be filled to about one-fourth of its height with the concrete which shall then be puddled, using 20 to 30 strokes of a ½-in. pointed rod. The filling shall be completed in successive layers similar to the first and the top struck off so that the mold is exactly filled. The mold shall then beremoved by being raised vertically, immediately after being filled. The molded concrete shall then be allowed to subside until quiescent and the subsidience of the specimen measured. For concrete to be finished by a mechanical tamping machine the slump shall not be less than ½ in. nor to exceed 1 in. If the concrete is to be finished by hand methods the slump may be as much as 1½ in. Experience in determining the consistency of concrete with the truncated cone apparatus would indicate the following "slumps:" Very dry consistency, no "slump;" fairly dry consistency, ½ to 1 in.; medium to wet consistencies, 1 to 4 in.; wet to sloppy consistencies, 4 to 8 in.; very sloppy consistencies, above 8 in.

(*c*) *Bureau of Standards, Jigging or Flow Table Test.*[2] The Jigging Test developed by the Bureau of Standards employs a table top raised vertically to a fixed height by means of a cam working at the end of a vertical shaft. A mass of concrete is molded in the center of the table in a sheet metal mold which has the shape of a hollow frustum of a cone. For aggregates up to 2 in. maximum size

[1] *Proceedings*, Am. Soc. Testing Mats., Vol. 25, Part 1 (1925). p 746

[2] For a description and illustration of one design for a flow table, see *Proceedings*, Am. Soc. Test. Mats. Vol. XX, Part II, p. 242 (1920), and "Concrete," June, 1920, p. 274.

this cone has a height of 5 in., upper diameter of 6¾ in. and lower diameter of 10 in. For smaller aggregates a mold having a height of 3 in., upper and lower diameter of 4 in. and 6 in. respectively may be used. After molding with as little tamping as is needed to fill the form, it is withdrawn and the table top is raised and dropped 15 times in about 6 seconds through ½ inch after which the new diameter of the mass is measured. Usually the mass flattens and spreads concentrically. Two diameters at right angles, the long and the short if difference is apparent, are measured by means of a proportional caliper which is so graduated that the sum of the two readings gives directly the "relative flowability," which may be expressed as the new diameter, divided by the old, multiplied by 100.

Using a mass of the size and shape described above we find that a flowability of 180 is probably as stiff a concrete as can be chuted and placed for reinforced concrete work in practice. A flowability of 240 is probably as great as is ever needed or should ever be permitted since the addition of more mixing water may result in excessive segregation.

(*d*) *Bureau of Public Roads: Plate Test.*—The plate test developed by the Bureau of Public Roads is based upon the principle that the consistency of concrete may be determined by weighing the amount retained upon a circular plate of a given diameter when the concrete is deposited there or in a standard manner. Approximately 45 lb. of wet concrete is caused to be dropped from the lower end of a hopper through a distance of 12 inches onto a 12 inch diameter circular plate. The weight of concrete remaining upon the plate is taken as the plate index of consistency.

Experiment E-12

Acceptance Tests of Fine Aggregates

Samples of sand are submitted for testing purposes. It is desired to know their suitability for use in cement mortar and concrete.

Before the performance of any of the tests, it is essential that each student assigned to this experiment familiarize himself with the methods as given in the Laboratory Manual or other references. He shall then discuss the details of conducting the tests with the instructor in charge.

As a guide to the various tests the following data and notes are given:

References.—A.S.T.M. Proceedings and Standards.
Laboratory Manual.
Indiana State Highway Specifications.

Joint Comm. Concrete Report 1924

Test 1.—Determination of Silt and Clay.

Laboratory Manual, Exp. E-2, p. 97, Method 3. Need not save wash water, but instead pour it through a 200 mesh sieve, saving all material caught upon this sieve. Dry and weigh residue.

Test 2.—Mechanical or Sieve Analysis.

Use residue from the wash test as sample for sieve analysis.

Manual, Exp. E-7 and E-8. Use A.S.T.M. sieves, Specification C 41–24, Nos. 4, 8, 16, 30, 50, 100 and 200 mesh. 500 gram sample; Ro-tap machine. Draw sieve analysis curve from percentages passing each sieve.

Test 3.—Strength of a 1:3 Mortar.

Manual Exp. F-1, p. 134, Method except as follows:
Sands: A. Sand as submitted.

B. Sand 0—8 mesh in size (screen from sand "A").

C. Sand 0—16 mesh in size (screen from sand "A").

D. Standard Ottawa sand.

900 grm. sand will be enough for 6 briquettes.

Specimens: 6 briquettes from each mix (3. @ 7 days, 3 @ 28 days) or 2″ × 4″ cyls. or 2″ cubes if desired.

Test 4.—Colorimetric Test for Organic Matter.

Manual, E-2, p. 98. Method 4. Original sand only.

Test 5.—Weigh per Cubic Foot (Rod Method).

Manual E-3, p. 99. Use 8″ dia. × 8″ measure = 1 cu. ft.

4.23

Test 6.—Specific Gravity (Exact and Approximate Methods).

Exact: Jackson Test. Follow A.S.T.M. 1921 Standards, p. 715; Manual, E-4, p. 103, Method (b), and page 105, Method 5.

Test 7.—Voids.

Manual, E-5, p. 105,

ARTICLE 6

Proportioning Mortars and Concretes

Information E-13

Theory of Proportioning Concrete

A critical study of methods of proportioning concrete is at present (1920) under way. The problem may be thus stated:

For construction:

Given Conditions.—1. The strength. 2. The consistency. 3. The expected aggregate, (which may vary in sizing of particles).

Factors to Be Adjusted.—1. The amount of cement. 2. The amount of water. 3. The relative proportions of fine and coarse aggregate.

1. The usual practice is to specify the *arbitrary mix* of 1–1½–3, 1–2–3, 1–2–4, 1–3–6, thus decreasing the proportion of cement as a weaker concrete is desired. The sizes of the aggregates are specified in advance.

2. Formerly a rough idea of the mix was obtained from the measured *voids* in the aggregate. Void determinations are subject to so many errors that this method is not used.

3. *The method of volumetric synthesis* uses trial mixtures. That mix is selected which will produce the densest concrete, *i.e.*, one which will yield the least volume in relation to the quantities entering into the mix.

4. Proportioning by adjusting the relative amounts of the particles of different sizes to follow the distribution indicated by an ideal curve, as for instance an ellipse.

5. Proportioning gravel concrete by increasing the cement when the per cent. of sand in the aggregate increases. Deposits of gravel necessarily vary in relative amounts of sand and pebbles. Usually there is an excess of sand which may all be used, if a richer mix is specified. Crum's Method (see Am. Soc. T.M.) gives the amount of cement to produce a concrete of standard quality. The amount of sand and its weight must be measured. (See Table Rec. by Crum, Amer. Soc. for Test Mat. 1919, pp. 462.)

6. *Proportioning by Surface Area*, Edwards and Young, (see Proc. 1918 A.S.T.M.) indicate that the surface area of the aggregate is the most important determining factor in the proportioning. The cement paste must cover the surface of the particles. The surface area is actually calculated, for example 700 sq. ft. per 100 lb. of aggregate.

An amount of cement is supplied to fit the job, thus for a first class concrete 2½ lb. of cement for each 100 sq. ft. of surface, or in this case, 7½ lb. cement for 100 lb. of aggregate, or roughly 0.186 of cement per 100 lb. of aggregate, or roughly 1:4.6. For details of this process see Experiment E-14.

7. *Proportioning by Fineness Modulus*—Abrams (Bulletin No. 1. *Structural Materials Research Laboratory, Lewis Institute, Chicago*) discovers that a certain gradation of aggregate accompanies the maximum strength. The gradation is expressed by the Fineness Modulus.

The Fineness Modulus is calculated thus—

Sieve a sample of the aggregate through the following set of Tyler sieves: 1½, ¾, ⅜, Nos. 4, 8, 14, 28, 48, 100. Add the percentages retained on the sieves and divide by 100. The Fineness Modulus is an expression of the area under a curve representing the sieve test. Evidently a number of curves, sizings of fine and coarse aggregate rather than one ideal curve, will produce a given Fineness Modulus, and therefore a given strength. If the Fineness Modulus and water-ratio are kept constant, a constant strength will result. But if the consistency is changed by the addition of water, the cement must be increased to preserve constant the water-ratio. See Experiment on Fineness Modulus, E-15.

8. *Joint Committee Recommended Method.*

Procedure:

Use judgment in the determination of the quality of concrete desired; *i.e.*, the strength desired.

Determine the consistency or degree of wetness necessary for the particular work and conditions. This is measured by the slump test.

Determine the maximum size of the fine aggregate and the maximum and minimum size of the coarse aggregate.

"(1) Not less than 15 per cent. shall be retained between the sieve which is considered, the maximum size and the next smaller sieve."

"(2) Not more than 15 per cent. of a coarse aggregate shall be finer than the sieve considered as the minimum size."

"(3) Only the sieve sizes given in the table shall be considered in applying Rules (1) and (2)."

The proportions as Portland Cement: Fine Aggregate: Coarse Aggregate: are given in the table of Report, for the desired strength under the headings for the desired slump and for the fine aggregate and coarse aggregate determined.

9. *Method Proposed by Com. C-6 of American Concrete Institute.*

Procedure:

(1) Select an aggregate the size of the largest particle being as large as the work will permit.

(2) Determine the ratio of fine to coarse aggregate which will produce the greatest density. See Assignment E-3.

(3) Add cement and water in a predetermined ratio, dependent upon the strength desired, to the aggregate to produce a mixture of such plasticity as is most suitable for proper depositing in the work. See Abram's curve showing relation between strength and water-cement relation.

(4) From the weight of the unit volume of the concrete thus produced and the weights of the ingredients it contains, derive the proportions.

Experiment E-14

Proportioning Concrete by Method of Sieve Analysis

The cases which may arise are in general, the following:

Case 1.—A single aggregate is separated into two or more sizes and re-combined.

Case 2.—Two or more aggregates are to be combined.

(*a*) When their analysis curves meet, but do not overlap.

(*b*) When their analysis curves wholly or partly overlap.

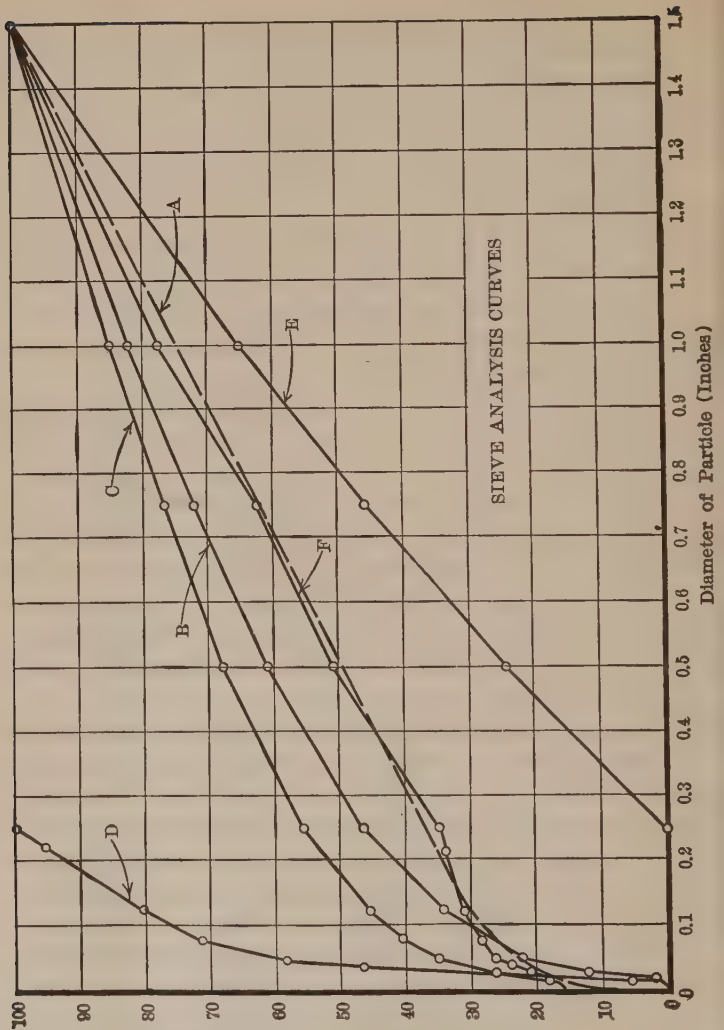
Procedure. *Case* 1.—Perform the operation of mechanical sieving upon the aggregate and draw sieve analysis curve together with curve for ideal mixture as directed in Experiment E-8.

Study the curves to decide how many and what sizes to screen the aggregate into so that the re-combination of parts may be as near as practicable to the ideal curve.

Note.—It is not practicable in most cases, on account of extra expense, to screen into more then three sizes of aggregate.

Now treat each size of aggregate as a complete sample and re-draw its curve to the original scale. This is most easily done by manipulation of values by slide rule. See Fig. 28*a*.

There are now represented on diagram sheet, two or more aggregates, as the case may be, whose curves do not overlap in sizes, and drawn to the same scale. These should be combined according to the demands of the ideal curve for the mixture.


SIEVE ANALYSIS CURVES
Per Cent Smaller than Given Diameter.
Diameter of Particle (Inches)
A
B
C
D
E
F
0
10
20
30
40
50
60
70
80
90
100
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

Give the percentages of each to use and draw the combined curve. For methods, see Reinforced Concrete Construction, Vol. I by Hool, p. 7. or Concrete, Plain and Reinforced, p. 190–200 by Taylor and Thompson.

Give the proportions by weight for an assumed concrete, *i.e.*, 1 to x concrete.

Case 2.—(*a*) Perform the operations and draw the curves as in Experiment E-8. The curves of the different aggregates should be drawn to the same scale on the same sheet. The Ideal curve for the mixture should be drawn from the 100 per cent. point on the ordinate of the largest size of particle and the coarsest aggregate. The method of combining the different aggregates is given in Case 1.

(*b*) Perform the operations and draw the curves as directed in E-8 and (*a*) above.

For method of combination and drawing combined curves see Concrete, Plain and Reinforced, by Taylor and Thompson.

Illustration of Method of Proportioning Concrete by Sieve Analysis

In Fig. 28*a* the following curves are shown:

Curve A represents the ideal curve of maximum density for a mixture of cement, sand and gravel where the size of the largest particle is 1½ in.

Curve B represents an ordinary "Run of Bank" sample of gravel in which the size of the largest particle is 1½ in.

Curve C represents a 1 to 5 (by weight) mixture of cement and gravel as shown in Curve *B*.

Curve D represents the sand finer than ¼ in. in the Run of Bank gravel, plotted to the same scale.

Curve E represents the gravel coarser than ¼ in. in the "Run of Bank" as represented by Curve *B* and plotted to the same scale.

Curve F represents a 1 to 5 (by weight) mixture of cement and sand as represented by Curve *D* and gravel as represented by Curve *E*.

Any mixture of cement and the run of bank gravel as represented by Curve *B*, will be far from the ideal maximum density mixture as represented by Curve *A*. If, however, the run of bank is screened into two parts, *i.e.*, sand finer than ¼ in. represented by Curve *D* and gravel coarser than ¼ in. represented by Curve *E*, the mixture of cement plus aggregate may be made to conform closely to the ideal. The ratio of cement to aggregate must be assumed in any case and depends upon the quality of concrete desired. In Fig. 28*a* the ratio of cement to aggregate was assumed to be 1 to 5 by weight. In any mixture of 1 to 5 concrete the cement is 1 divided by 6 equals 16.6 per cent. by weight of the whole. The ideal calls for 37 per cent. finer (equals sand plus cement) than a ¼ in. size and 63 per cent. coarser than ¼ in. size. To give a still closer approach to the ideal 35 per cent. finer than ¼ in. and 65 per cent. coarser than ¼ in. were taken.

The mixture, to conform closely to the ideal, will have then 35 per cent. by weight finer than ¼ in. and this will be made up of sand plus cement, and since the cement in a 1 to 5 mixture is 16.6 per cent. of the whole, then $35 - 16.6 = 18.4$ per cent. is the per cent. by weight of sand smaller than ¼ in. in the mixture. The proportions of cement, sand, and gravel for the total mixture of 1 to 5 concrete are then 16.6 per cent. cement, 18.4 per cent. sand as represented by Curve *D* and 65 per cent. gravel as represented by Curve *E*. This corresponds to

the proportion by weight of 1:1.1:3.9. The proportions by volume as used on the work will be determined from the unit weights of the materials. The bulking effect of moisture should be taken into account in this transformation of proportions. See Exp. E-3 and E-6. And the curve of the mixture (Curve *F*) is seen to conform much closer to the ideal maximum density curve than a 1 to 5 mixture (Curve *C*) of cement and the original "Bank Run" gravel.

Experiment E-15

Experiment on Surface Area of Aggregates

References.—Proceedings of Amer. Soc. for Testing Materials, Vol. 18, page 235 and Vol. 19, page 444.

The surface area of aggregates is sometimes used as a measure of their value for concrete. A coarse sand, for example, has less surface area to be covered with cement paste, and requires less water for mobility than a fine sand of equal volume.

Method of Determination of Surface Area.—1. Sieve a sample of gravel; determine its weight per cubic foot. Sieve it through the following Tyler sieves 1½, ¾, ⅜, No. 4, 8, 14, 28, 48, 100.

2. Count the number of particles per gram or fraction for extreme small sieves per ounce between the smaller intermediate sieves, and per pound between the larger sieves.

3. Determine the specific gravity of the aggregate and calculate the weight of solid cubic inch. See Exp. E-4.

4. Calculate the number of particles required to form this solid volume and therefrom the average volume of one particle.

5. Assuming this volume to be a sphere, calculate its diameter and surface area, and total surface area of the particles per unit weight.

6. Express the result in square feet per 100 lb. of aggregate between each sieve and for entire sample.

The following formula may be conveniently used:

$$A = 236.1\sqrt[3]{\frac{N}{S^2}}$$

where A = Surface Area in square feet per 100 lb.
S = Specific Gravity of material.
N = Number of grains per gram in any size of separation.

7. Make graph with diameter of particle as abscissa and square feet per 100 lb. as ordinate. If 3 lb. of cement are to be used for every 100 sq. ft. of surface of aggregate, how many bags of cement will be used to a cubic yard of this mixed aggregate?

With water ratio of 0.85, how many gallons of water per bag of cement? If the proportions are stated in terms of mixed aggregate, as 1:4.2, how can this be expressed in terms of separate volumes of sand and coarse aggregate?

The Hydro-Electric Commission of Ontario proportions concrete on the basis of surface area. (See Engineering News-Record, Vol. 84, page 33.)

Experiment No. E-16

Experiment on Fineness Modulus

References.—Bulletin No. 1. Lewis Institute. Johnsons Materials of Engineering.

The Fineness Modulus is used as an expression of that gradation of sizes of aggregates which will produce good concrete. A Fineness Modulus of 5½ to 6 is favorable.

With same aggregate as in Experiment No. E-14 on Surface Area, determine the Fineness Modulus, *i.e.*, the sum of the per cents. retained on the sieves divided by 100. See pages 110 and 121 in the manual.

(1) Report Fineness Modulus of sand and pebbles separately and combined.

(2) Report per cent. of sand and pebbles in mixture.

(3) Check application of following formula.

Fineness Modulus of mixed aggregate = F. M. of sand $\times$ per cent. of sand + F.M. of pebbles $\times$ per cent. of pebbles.

Work following numerical problems.

(1) The F. M. of sand is 3.05, and of pebbles is 7.50. Required per cent. of sand to produce a mixed aggregate whose F. M. is 6.0.

(2) When sand and pebbles are mixed the resulting volume will be about 0.86 of the total separate volumes, (*a*) a mix of 1:2:4 will be a proportion of $1:6 \times 0.86$ or 1:5.16 combined, (*b*) a mix of 1:4.2 combined aggregate will be what? When expressed as separate or loose volumes? $\frac{4.2}{.86} = 4.9$ loose volumes.

The aggregate sieves to show 40 per cent. sand and 60 per cent. stone. Therefore—

4.9×40 per cent. = 1.96 sand

4.9×60 per cent. = 2.94 sand, or approximately 1:2:3

(3) Concrete for a road construction is specified to be mixed 1:2:3, that is 40 per cent. sand and 60 per cent. pebbles. The available sand is finer than the specifications allows. What should new proportions be for a concrete of equal strength, and the fine sand used? Tests on the aggregate show the following:

F. M. fine sand = 2.40 Weight lb. per cu. ft. = 102
F. M. coarse sand = 3.30 Weight lb. per cu. ft. = 116
F. M. pebbles = 7.25 Weight lb. per cu. ft. = 112

Weight of mixed aggregate with coarse sand = 130 lb. per cu. ft.

Calculations.—Real Mix = 1: (2 + 3) 0.86 = 1:4.3.

F. M. of mixed aggregate (coarse sand) = $3.30 \times .40 + 60 \times 7.25 = 5.67$.

The F. M. of the aggregate with fine sand must also be 5.67. Per cent. fine sand =

$$\frac{7.25 - 5.67}{7.25 - 2.40} \times 100 = 32.5 \text{ per cent.}$$

$$\text{Per cent. of pebbles} = \frac{67.5}{100.0} = 67.5 \text{ per cent.}$$

The mix will be as before 1:4.3 mixed or 1:5 loose volumes.

The proportions will be

Sand $5 \times .325 = 1.62$

Pebbles $5 \times .67 = 3.38$, or 1:1.62:3.38.

We have thus added coarse material by adding more pebbles. This mix should be tested to see if it works properly on the job.

Repeat this calculation for the material tested in this experiment.

Experiment E-17

Proportioning Materials for Concrete (A.C.I. Comm C-6)

References.—Standard Specifications for Concrete and Reinforced Concrete, Joint Committee; 1924 Standards of A.S.T.M.; Manual; Bulletin No. 1 of Lewis Institute.

Materials.—Coarse and fine aggregates. Mixture of 3 brands of portland cement.

Apparatus.—½ Cubic foot measure.

Method.—1. Select an aggregate the size of the largest particle being as large as the work will permit.

2. Determine the ratio of fine to coarse aggregate which will produce the greatest density. (Manual E-3, Rod Method.)

3. Add cement and water in a predetermined ratio to the aggregates to produce a mixture of such plasticity as is most suitable for proper depositing in the work.

Procedure.—1. Determine the weight per cubic foot of the fine and coarse aggregates, and mixtures of fine and coarse aggregates when the fine aggregate is 25, 30, 35, 40, 45 and 50 per cent. of the total aggregates (E-3).

2. Dump about 1 cubic foot of the combination of fine and coarse aggregates, which yields the greatest density, into the mixer.

3. Add a sufficient known amount of water and cement in a ratio of .... to produce a consistency of concrete to give a cone slump of .... inches. (See Note.)

4. Mix 1 minute in a batch mixer, and then measure the volume of mixed concrete and determine the cone slump.

5. Make 6″ × 12″ cylinders of concrete. Cap with neat cement.

6. Cure in damp sand and test in .... days.

7. Determine proportion of cement, fine and coarse aggregates used in batch.

NOTE.—Use a water-cement ratio which will give a strength of —— lb. per sq. in. when calculated from Abrams average Strength-Water Cement Ratio curve as represented by the equation

$$\text{Strength} = \frac{14{,}000}{7^x}$$

where x is the water cement-ratio.

Article 7

TESTS OF CONCRETE AND OTHER BRITTLE MATERIALS

Experiment F-1

The Value of a Sand or Other Fine Aggregate as Shown by Strength Tests

Purpose.—This test is to determine the strength of a natural sand mortar as compared with strength of a standard Ottawa Sand Mortar.

Note that fine soluble limestone dust from quarry screenings may cause failure in a structure, without showing defects in this test.

References.—Indiana State Highway Common Specification in appendix, page 163.

Joint Comm. Report 1924

Material.—Any sand or fine material used as a concrete aggregate. This material should all pass a ¼-in. sieve. The original moisture in the sand should be present if possible, in which case a correction for weights must be determined by drying a separate sample.

The cement used should be a mixture in equal parts of several standard Portland cements.

Method.—In determining the strength, nine test specimens of standard Ottawa sand and cement in the proportion of 1 part cement by weight to 3 parts Ottawa sand, should be made in the regular way. See Experiment D-6 and D-7.

The same number of specimens should be made using the sand under test. The correction for weight due to moisture should be made. This damp sand should first be thoroughly mixed with the required amount of cement until the whole is a uniform color. Water should then be added until the consistency is the same as that of the standard sand mortar. Care should be used in this determination.

Test 3 at 72 hours, 3 at 7 days and 3 at 28 days age. Report the strength of each and the average of the three.

Report.—The report should be in standard form. The ratio of the strength of the test sand to that of the standard sand mortar should be noted.

If the sand proves to be defective what tests should be made to ascertain the cause?

Experiment F-2

(See also Exp. F-3)

Compressive Strength of Concrete

The object of this experiment will be to determine the compressive strength of concrete.

References.—Hool & Johnson "Concrete Engineers Handbook."

Baker's Masonry Construction.

Material.—Use broken stone (or gravel) up to 1½ in. sand and Portland cement.

Apparatus.—Six cylindrical molds.

Method of Making Test Specimens.

1. Compression tests of concrete shall be made of cylinders of a diameter equal to one-half the length. The standard shall be 6 by 12-in. cylinders where the coarse aggregate does not exceed 2 in. in size; for aggregates

larger than 2 in., 8 by 16-in. cylinders shall be used; 2 by 4-in. cylinders may be used for mixtures without coarse aggregate.

2. Laboratory Hand mixing.

(*a*) Concrete shall be mixed by hand in batches of such size as to leave a small quantity of concrete after molding a single test piece. The batch shall preferably be mixed in a shallow galvanized steel pan with a 10-in. bricklayer's trowel which has been blunted by cutting off about 2½ inches of the point, as follows:

(*b*) The cement and fine aggregate shall be mixed dry until the mixture is homogeneous in color;

(*c*) The coarse aggregate shall be added and mixed dry;

(*d*) Sufficient water shall be added to produce concrete of the required workability;

NOTE.—Concrete tests should be made on *plastic* mixtures. It is of the utmost importance that a uniform degree of workability be secured in tests involving comparisons of different materials and methods.

(*e*) The whole shall be mixed thoroughly until the entire mass is homogeneous in appearance.

3. The workability or plasticity of each batch of concrete shall be measured immediately after mixing by one of the following methods: See Exp. E-11.

4. Concrete tests pieces shall be molded by placing the fresh concrete in the form in layers 3 to 4 in. in thickness. Each layer shall be puddled with 25 strokes with a ⅝ in. round steel bar of a length 9 in. greater than the length of the mold, pointed at the lower end. After the top layer has been puddled, the surplus concrete shall be cleaned off with a trowel, and the mold covered with a machined metal plate or a piece of plate glass at least ¼ in. thick, which will be used later in capping the test piece.

5. Two to four hours after molding, the test pieces shall be capped with a thin layer of stiff neat cement paste in order that the cylinders may present a smooth end for loading. The cap shall be formed by means of a machined metal plate or a piece of plate glass of suitable size, at least ¼ in. thick, worked down on the fresh cement paste until it rests on the top of the cylinder form. The cement for capping shall be mixed to a stiff paste before beginning to mix the concrete; in this way the tendency of the cap to shrink will be largely eliminated.

In computing amounts necessary use the rule shown on p. 111, or obtained by methods shown in Experiments E-15 or E-16.

For method of mixing, see Experiment E-9 or E-10. Tamp concrete in cylinders in layers of 4 in. A ⅝ in. diameter steel rod is recommended for rodding the concrete into place. Carefully smooth off the top and make cylinder stand vertical. Be sure top and bottom bases are both perpendicular to axis of cylinder. Test in 7 or 28 days. For method of test see F-3 and F-4.

Experiment F-3

Compression Test Brittle Materials

The purposes of this experiment are: To obtain knowledge of the proper methods of testing materials in compression; of the crushing strength of such materials; and of the characteristic forms of fracture.

Material.—Three concrete cylinders, or three bricks, or terra cotta, or any building material in proper form for compression test.

Preliminary.—(1) Before testing any specimen carefully measure its height and cross section.

2. When brick, stone, concrete, or cement specimens are to be tested they should be carefully bedded either with blotting paper or with plaster of Paris. (See Fig. 6.) To bed a specimen with plaster of Paris, have the testing machine balanced, and the head down so far that it will clear the specimen only about 1 in. or 2. Then mix some plaster of Paris and water to a very thick, creamy consistency. Spread a thin layer of this on paper placed upon the spherical bearing block of the machine and cover it with a piece of tough sized paper, upon which the specimen should then be placed. The paper is to keep the water of the plaster out of the specimen. Upon another similar piece of paper a similar pad of the plaster should be spread covered with another piece of paper to form a pad, and the pad then placed upon the specimen. The head of the machine should then be run down rapidly until it presses upon the plaster sufficiently to cause it to flow, thus insuring a good bedding. With the trowels now fill up all the open spaces about the edges of the specimen near the faces of the machine. The surfaces of the specimen may be shellaced and the plaster of Paris applied directly to them. If it is not desired to cap the specimen in the testing machine, oiled plate glass may be used to give a smooth plane bearing surface on the plaster of Paris. After letting the plaster set until hard, the specimen is ready to be compressed. Have the work inspected by the instructor before proceeding.

Another method of capping specimens is as follows: Make a paste of neat cement or rich mortar at or before making the concrete and place the paste on the specimen after 2 or 3 hours has elapsed. This should then be

covered by plate glass or other plane surface until the paste hardens.

In the case of all materials see that the ends of the specimen admit of a good even bearing in the machine.

The Test.—Using the slowest speed available about 0.05 inches per minute when the machine is running idle, now compress the specimen, meanwhile keeping the scale beam floating; and watch carefully the behavior of the specimen.

Computation.—Compute the stress in pounds per square inch at first crack, and at maximum load.

Results.—Load and crushing strength at first crack and at maximum load or failure, Sketch form of fracture.

Comparison of results with standard values.

See general form of report.

Experiment F-4

Compression of Brittle Materials with Deformation Measurement

References.—Walker on "Modulus of Elasticity of Concrete" Proceedings A.S.T.M. Part II, 1919.

Hool, Reinforced Concrete Vol. I.

Object.—In addition to determining the maximum strength in compression, as in other compression tests, it is intended in this experiment to find the strength at elastic limit, the modulus of elasticity, and the modulus of elastic resilience.

Material.—The material should be of a cylindrical form if possible. A gage length of at least 8 in. should be available.

Apparatus.—Compressometer reading to 0.0001 in.

Operations in Testing.—Proceed as in other compression tests except that the load is applied in increments of

—pounds (about one-twentieth of the probable maximum load) and the total amount of compression at each increment is measured by a compressometer. (Use slowest speed of the machine.)

Computations.—Plot points with unit load in pounds per square inch for ordinates and unit compression in inches per inch for abscissæ. Draw a straight line averaging the points preceding the elastic limit, if any; and, tangent to this straight line, draw a smooth curve averaging the remaining points. Mark the points of maximum load and elastic limit, which latter is the point of tangency of the straight line and the smooth curve. Then draw a line through the origin parallel to the straight line previously drawn through the plotted points. (Do not continue this line beyond elastic limit.) Mark the point of elastic limit, if any, on corrected line.

Consult above references for various methods of computing Mod. of Elasticity.

The moduli of elastic resilience and of rupture-work are the work done on each cubic inch of material in deforming it up to the elastic limit and ultimate strength respectively. These moduli may be obtained from the curve of plotted points by multiplying the area under the curve up to the point considered by the scale value of each unit area of the coordinate paper or by computation from observed data.

Experiment F-5

Reinforced Concrete Beam Test

References.—Concrete Plain & Reinforced by Taylor, Thompson & Sonulski. Concrete Design by Urquhart & O'Rourke.

Note.—This experiment may be made to apply to beam or slab tests by changing certain details as to

shape and arrangement of specimen and reinforcement and also measurement of deformations.

This experiment follows or is accompanied by compressive strength test. The same proportions will prevail. The object of this test is to investigate the action of a reinforced concrete beam.

Material.—Same as in Experiment F-2 with the addition of steel for reinforcement.

Method of Making and Test.—Make concrete as in Experiment F-2 only a little wetter method of proportioning will be as in E-12. Place two tapering wooden plugs on bottom of forms under each reinforcing rod and spaced 10 inches center to center in middle of length of beam. Wet forms and cover bottoms of mold with about 1 in. of concrete, then place the rods in position. Ram and spade the concrete well about forms and rods. Level off the top and cover with damp cloth. Sprinkle every day for ten days.

For compression measurements small iron or brass plugs should be set flush with top of concrete, directly over the reinforcement and spaced 10 inches center to center in the middle of the beam. Drill holes in the reinforcing and plugs as directed.

The test will be under supervision of the instructor. Determine the load-deflection curve and stress in steel and concrete, if possible, by means of the Berry strain gage.

Draw curves for each beam on the same sheet with total load as ordinates and stresses in the steel and in the concrete as abcissæ.

Report will cover: 1. Description of materials, kind, brand, voids, strength of cement, etc. 2. Methods for obtaining proportions. 3. Design of beam. 4. Per cent. of steel. 5. Stresses in concrete and steel at safe design

load first crack and maximum by formula, and by test. 6. Location of neutral axis by graphical method.

Experiment No. F-6

Bond Strength of Steel in Concrete

Bond strength is the resistance to withdrawal offered by the surface of a steel bar embedded in concrete. At low loads this resistance arises from the adhesion between steel and the film of cement, as in case of a polished bar. When this is overcome, the roughness of surface introduces bearing and shearing resistance, as in case of a deformed bar with shoulders. An ordinary plain bar with uneven surface is a partially deformed bar.

Select two round rods 20 in. long and ½ in. in diameter from each of the following: cold drawn steel with smooth surface; ordinary plain reinforcing steel; deformed bar. Embed these in cylinders. Pull out the bars at age of 28 days, observing (1) stretch of bar, and (2) withdrawal from concrete at increasing loads.

Draw curves of slip against bond stress per square inch of embedded surface. Report (1) bond stress at first slip, (2) maximum bond, (3) stress in bar at maximum bond, and (4) number of diameters of length of embedment necessary to develop maximum strength of bar.

Did the cylinder split? Did the bar reach its yield point?

Consult references and report how the results would have varied with richer concrete and bars of square or oblong shape.

Experiment No. F-7

Test of Concrete Reinforcing Fabric

Report on sample furnished the following: Weight per 100 sq. ft.; ultimate strength of metal; distribution

of area of cross-section between longitudinal and transverse directions.

Consult catalogue of manufacturer and determine uses for which this fabric is recommended.

Report.—See standard form.

Experiment F-8

Cross Bending and Compression Tests of Building Brick

Reference.—Tentative Specifications for Building Bricks. A.S.T.M., 1924, Standards p. 665 I.

Purpose.—The purpose of the tests is to determine the quality of various grades of building bricks.

Materials.—Various kinds and grades of building brick as assigned. At least five of each kind should be available for each test.

The bricks should be dried to constant weight.

Procedure.—

Transverse Test.—Test flat-wise on a span of 7 in. with the load applied at midspan. Use standard apparatus. Determine maximum breaking load.

Compression Test.—Test half-brick on edge.

1. Cut the brick into halves with mason's chisel.
2. Apply coat of shellac to upper and lower edges and allow to dry.
3. Apply thin coat of plaster of paris mixed with water to the consistency of thick cream.
4. Apply oiled plate glass and allow to harden.
5. Test in compression using spherical bearing block. Determine the maximum breaking load.

Report.—Follow the standard form referring to the above reference for computations and specifications.

Additional Reference: Bulletin No. 111, Bureau of Standards.

Experiment No. F-9

Tests of Re-inforced Concrete Columns

References.—Joint Committee Report for Concrete and Reinforced Concrete, 1924, pp. 57–61. Taylor, Thompson, and Smulski, Concrete Plain and Reinforced, p. 403.

Procedure.—The materials used and method of proportioning will be as in Assignment E-12.

Steel reinforcement should be available for one or more longitudinally reinforced columns with the proper lateral ties and for one or more longitudinally reinforced columns with spiral reinforcement. The reinforcement should be carefully wired in place before mounting in the column molds.

Care should be used in molding so that should be no air pockets or visible voids produced in the concrete.

Six inch by twelve inch short cylinders should be molded at the same time in order to give the strength of the plain concrete.

The Tests.—The tests will be made usually at 28 days' age. Readings of deformation of the column as a whole should be taken by means of suitable yokes and dials reading to 0.001 inches.

In certain cases readings of steel stresses in the steel may be taken by the Berry Strain gage.

Obtain the load at first visible crack in the concrete and also at maximum.

Note the behavior of the core of the spirally reinforced column.

Computations.—Draw a diagram with column load as ordinates and unit deformation as abscissae.

Compute the theoretical safe design load on each column.

Compute the relative stiffness of the different columns at the safe design load on the columns.

If taken, stresses in the steel should be computed from the strain gage readings. These should be compared with the theoretical stresses.

Report.—The report should be in standard form.

Article 8

TESTS OF ROAD MATERIALS

Experiment G-1

Rattler Test of Paving Brick

Purpose.—To determine the effects of impact and abrasion in a standard rattler test.

Note.—Differentiate these effects in comparing different samples of brick.

References.—Specifications of the American Society for Testing Materials, 1924, p. 654.—Judson—Roads and Pavements; Tillotson—Paving and Paving Materials; Baker—Roads and Pavements; Bryne—Highway Construction.—Specifications of N. B. M. A.

Extract from standards of A.S.T.M., 1924, p. 659. "The number of bricks per test shall be ten for all brick of so-called "block size" whose dimensions fall between 8 and 9 in. in length, 3 and 3¾ in. in breadth, and 3¾ and 4¼ in. in thickness."

Note.—Where brick of larger or smaller sizes than the dimensions given above for blocks are to be tested, the same number of brick per charge should be used, but allowance for the difference in size should be made in setting the limits for average and maximum rattler loss.

Note any surface evidences of lamination. Select brick which are free from chipped corners and other defects.

Apparatus.—The standard rattler of the Amer. Soc. for Testing Materials shall be used. (See Standards 1924 of Amer. Soc. for Testing Materials, p. 556.) The abrasive charge shall consist of cast iron spheres of standard composition and of two sizes. Ten large spheres 3.75 in. in diameter when new weighing approx. 7.5 lb. each. The smaller spheres shall be 1.875 in. in diameter when new. The collective weight of the charge shall be as nearly 300 lb. as possible.

Procedure.—Weigh and place the required number of bricks in the rattler. See that the shot makes up the required weight for each size; if they do not, place an additional small shot in the rattler. Record the reading of the counter. Close the rattler and start. Note the rate which should be as near 30 r.p.m. as possible. Only one start and stop per test is generally acceptable.

Results.—The loss shall be calculated in percentage of the initial weight of the brick composing the charge. In weighing the rattled brick, any piece weighing less than 1 lb. shall be rejected.

Report should be in general form.

Experiment G-2

Absorption Test

Procedure.—Place 5 rattled brick in dry kiln 48 hours and weigh each brick separately to nearest gram. Then place in water completely submerged at temperature between 60° and 80°F. Heat water to boiling within one hour and boil for 5 hours and then allow to cool to

a temperature between 60° and 80°F. Place strips $\frac{1}{2} \times \frac{3}{4}$ beneath the bricks and between them so that faces shall not be in contact. When removed from water, allow the water to drip from the surfaces for about 2 minutes, then weigh separately to nearest gram. (Note: When rattled brick are not available, use half-brick.)

Absorption.—Subtract the weight of the dry bricks from the weight of the wet bricks. Find the per cent. of gain in weight, which is called the per cent. of absorption.

See general form of report.

Experiment G-3

Abrasion Test of Rock for Road Materials and Ballast

This test is intended to determine the wearing value of road materials.

References.—1924 Standards of American Society for Testing Materials, p. 923.

Bulletin, No. 347, U. S., Dept. of Agriculture. Office of Public Roads.

Materials.—Any rock or like material used in road construction. At least 30 lb. of the material should be available for a test.

Procedure.—The material to be tested should be broken in pieces as nearly uniform as possible. There should be 50 pieces in the charge, the total weight of which shall be 5 kg. All test pieces shall be washed and thoroughly dried before testing. The charge is then placed in the Deval Abrasion machine and given 10,000 revolutions at the rate of 30 to 33 r.p.m.

The Deval Abrasion machine consists of one or more hollow iron cylinders, closed at one end and furnished

with a tightly fitting cover at the other. The cylinders are 20 cm. in diameter and 34 cm. in depth inside dimensions. They are mounted on a shaft at an angle of 30° with the axis of rotation of the shaft.

At the end of 10,000 revolutions, the charge is removed and those particles retained on a $\frac{1}{16}$-in. mesh sieve, are thoroughly washed and dried again.

Computations.—Compute the wear in per cent.

Compute the French Coefficient of wear.

The French Coefficient of wear for any material $= 20 \times \frac{20}{W} = \frac{400}{W} = \frac{40}{\text{per cent. of wear}}$ where W equals the loss in weight under $\frac{1}{16}$-in. in size per kilogram of rock used.

Experiment G-4

Cementation Test of Rock or Gravel or Materials of Like Nature

This test is intended to determine the comparative value of dust from different rocks or gravels as a binder in the surface of roads.

Materials.—The materials consist of 1500 grm. of coarsely crushed rock broken to pass a $\frac{1}{2}$-in. sieve or 1500 grm. of gravel as it comes from bank.

Special Apparatus.—A Ball Mill for grinding the materials. Cementation impact machine for testing briquettes.

Procedure.—Place 500 grm. of the rock together with 90 c.c. of water in the ball mill. The mill is then revolved at the rate of 30 revolutions per minute for two and one-half hours, the action of the chilled iron balls in the mill grinds the sample to a stiff dough.

Place about 25 grm. of the dough in the cylindrical metal die for molding. The die is 25 mm. in diameter.

By applying a load directly to the plunger of the die, run the plunger down to a maximum pressure of 132 kg. per square centimeter. This load is applied only for an instant and then released. Remove the briquette and measure the height, if it is not 25 mm. in height, the requisite amount of material should be added or subtracted to make the next briquette the required height.

At least 5 briquettes should be made from each sample. These are allowed to dry in room air for 20 hours and dried in air of approximately 100°C., for 4 hours. After cooling 20 minutes in a desiccator they should be tested in the impact machine.

The briquette is placed directly on the anvil under the plunger. By placing a drop of shellac on the anvil under the briquette, it can be made to stay in its position. After adjusting the recording paper and needle, the motor is started. The mechanism is such that the briquette receives the blow of a 1 kg. hammer at the rate of 60 per minute. The number of blows it takes to break the specimen is recorded on the drum.

The number of blows necessary to destroy the resilience of the briquette, so that no action is recorded on the drum, is taken as the cementing value of the specimen. There should be obtained an average of at least five specimens to fix the cementing value of the material.

Experiment G-5

Hardness Test of Rock Road Materials.—Dorry Test

This test indicates the comparative hardness of rocks as indicated by their ability to withstand an abrasive force.

Special Apparatus.—A diamond core drill for cutting out test pieces. A Dorry Abrasion Machine for testing hardness.

Materials to Be Tested.—Any rock in pieces large enough so that cylinders 25 mm. in diameter and about 25 mm. in hieght may be cut from them.

Procedure.—Cut out specimens from rock by means of a diamond core drill. The ends may be squared by the diamond saw. At least two and preferably four specimens should be tested from each material.

These specimens should be dried to a constant weight at 100°C. Before placing in the machine they should be weighed. After placing two specimens in the machine start the motor and allow to run for 1000 revolutions at 30 r.p.m.

Reweigh the specimens and determine the loss.

The operation is repeated with the specimen reversed.

Calculations.—Express the loss as a per cent. of the original dry weight. Compute the coefficient of hardness, by the formula:

$$20 - \frac{\text{loss in grams}}{3}$$

Experiment G-6

STANDARD METHOD OF TEST FOR TOUGHNESS OF ROCK
A.S.T.M. YEAR BOOK, 1924. PP. 924.

In this connection, toughness of rock is taken to mean the power to resist fracture by impact.

Special Apparatus.—A core drill 1 in. in diameter for cutting specimens.

An impact machine in which the anvil weighs 50 kg., the hammer weighs 2 kg., the intervening plunger weighs

1 kg. The plunger should bear upon the test piece with spherical surface of hardened steel having a radius of 1 cm.

Materials.—Quarry samples of rock from which test specimens are to be prepared shall measure at least 6 in. on a side and at least 4 in. in thickness, and when possible shall have the plane of structural weakness of the rock plainly marked thereon. Samples should be taken from freshly quarried material, and only from pieces which show no evidences of incipient fracture due to blasting or other causes. The samples should preferably be split from large pieces by the use of plugs and feathers and not by sledging. Commerical stone-block samples from which test specimens are to be prepared shall measure at least 3 in. on each edge.

Specimens for test shall be cylinders prepared as described in Section 4, 25 mm. in height and from 24 to 25 mm. in diameter. Three test specimens shall constitute a test set. The ends of the specimen shall be plane surfaces at right angles to the axis of the cylinder.

One set of specimens shall be drilled perpendicular and another parallel to the plane of structural weakness of the rock, if such plane is apparent. If a plane of structural weakness is not apparent, one set of specimens shall be drilled at random. Specimens shall be drilled in a manner which will not subject the material to undue stresses and which will insure the specified dimensions. The ends of the cylinders may be sawed by means of a band or diamond saw, or in any other way which will not induce incipient fracture, but shall not be shipped or broken off with a hammer. After sawing, the ends of the specimens shall be ground plane with water and carborundum or emery on a cast-iron lap until the cylinders are 25 mm. in length.

Procedure.—At least three and preferably four or more specimens should be tested for each rock. These should be dried in a constant weight before testing. The specimen should be adjusted in the machine, so that the center of its upper surface is tangent to the spherical surface of plunger. The test shall consist of 1 cm. fall of the hammer for the first blow and an increased fall of 1 cm. for each succeeding blow, till the piece is ruptured.

Calculations.—Compute the energy of the final blow. The toughness is represented by the number of blows necessary to break specimen.

APPENDIX I

Formulas in Mechanics of Materials

Tension.

Relative contraction of area at fracture equals

$$\frac{\text{Original area} - \text{area at fracture}}{\text{original area}}$$

Relative elongation in gage length equals:

$$\frac{\text{Length after fracture} - \text{gage length}}{\text{gage length}}$$

Tension and Compression.

Church's Mechanics.	Poorman's Strength of Materials.
$p = \frac{P}{F}$	$S = \frac{P}{A}$
$E_t = E_c = \frac{Pl}{F\lambda} = \frac{p}{\epsilon}$	$E = \frac{Pl}{Ae} = \frac{S}{\delta}$
$U = \frac{1}{2}T''\epsilon V = \frac{1}{2}\frac{T''^2}{E}V$	$U = \frac{1}{2}\frac{S^2}{E}V$
Mod. of Res. $= \frac{1}{2}\frac{T''^2}{E}$	Mod. of Res. $= \frac{1}{2}\frac{S^2}{E}$

Torsion (round solid shafts)

$p_s = \frac{Pae}{I_p} = \frac{Me}{I_p}$	$S_s = \frac{Tr}{J}$
$E_s = \frac{Pat}{\alpha I_p}$	$E_s = \frac{Tl}{J\vartheta}$
$U = \frac{1}{2}Pa\alpha$	$U = \frac{S_s^2 Jl}{2E_s r^2}$
	Mod. of Res. $= \frac{1}{4}\frac{S_s^2}{E_s}$

Cross Bending.

$p = \frac{Me}{I}$	$S = \frac{Me}{I}$
$p = \frac{3}{2}\frac{Pl}{bh^2}$ (Center Loading, Rectangular Section)	$= \frac{3}{2}\frac{Pl}{bh^2}$
$E = \frac{1}{48}\frac{Pl^3}{dI}$ (Center Loading)	$E = \frac{1}{48}\frac{Pl^3}{yI}$

$$E = \frac{23}{1296}\frac{Pl^3}{dI} \text{ (Third Point Loading)} \qquad E = \frac{23}{1296}\frac{Pl^3}{yI}$$

$$U = \frac{1}{2}Pd \qquad U = \frac{1}{2}Py$$

$$\text{Mod. of Res.} = \frac{1}{18}\frac{S^2}{E}$$

Impact Bending (Rectangular Beams). Approximate formulas.

$$p = \frac{GHl}{3bh^2\Delta}$$

$$E = \frac{GHl^3}{2\Delta^2 bh^3}$$

Road Materials Formulas

Deval Abrasion Test

$$\text{Loss per cent. (per cent. wear)} = \frac{\text{Original weight—final weight}}{\text{Original weight}}$$

$$\text{French coefficient of wear} = 20 \times \frac{20}{w}$$

Where w is the weight in grams of the detritus under 0.16 cm. ($\frac{1}{16}$ in.) in size per kilogram of rock used.

Hardness Test

Coefficient of hardness = 20 − $\frac{1}{3}$ loss in weight after 1000 revolutions at 28 r.p.m.

Legend for Above Formulas

	Church	Poorman
Width	b	b
Height	h	h
Gage length or span	l	l
Area of cross section	F	A
Moment of inertia	I	I
Polar moment of inertia	I_p	J
Radius of gyration	k	
Distance from neutral axis to extreme fiber	e	r
Total load (concentrated)	P	P
Unit stress	p	S
Unit stress at elastic limit tension	T''	
Total elongation in gage length at or before elastic limit	λ	e

	Church	Poorman
Unit elongation	ϵ	δ
Twist in gage length (radians)	α	θ
External moment in torsion	Pa	T
Deflection	d	y
Mod. of elasticity (tension and compression)	E	E
Mod. of elasticity (shear)	E_s	E_s
Resilience (work done on specimen)	U	U
Impact Bending:		
Weight of hammer	G	
Span length	l	
Fiber stress	p	
Modulus of elasticity	E	
Total height of drop	H	
Deflection (total) due to static load G + deflection due to blow	Δ	

APPENDIX II

Strength Specifications for Steel and Iron American Society for Testing Materials, Standards, 1924

Metal	Tensile strength, lb. per square inch		Minimum elongation, per cent.		Contraction of area per cent.
	Ultimate	Yield point	in 8 in.	in 2 in.	
Bridges:					
Structural steel	55– 65,000	30,000	$\frac{1,500,000}{\text{ultimate}}$	22	
Rivet steel	46– 56,000	25,000 min.	$\frac{1,500,000}{\text{ultimate}}$		
Buildings:					
Structural steel	55– 65,000	½ ultimate	$\frac{1,400,000}{\text{ultimate}}$	22	
Rivet steel	46– 56,000	½ ultimate	$\frac{1,400,000}{\text{ultimate}}$		
Ships:					
Structural steel	58– 68,000	½ ultimate	$\frac{1,500,000}{\text{ultimate}}$		
Boiler and fire box steel for locomotives:					
Flange steel	55– 65,000	½ ultimate	$\frac{1,500,000}{\text{ultimate}}$		
Fire box steel	52– 62,000	½ ultimate	$\frac{1,500,000}{\text{ultimate}}$		
Structural nickel steel:					
Rivet steel	70– 80,000	45,000	$\frac{1,500,000}{\text{ultimate}}$	..	40
Plates, shapes, bars	85–100,000	50,000	$\frac{1,500,000}{\text{ultimate}}$	18	25
Eye bars, rollers, unannealed	95–110,000	55,000	$\frac{1,500,000}{\text{ultimate}}$	16	25
Eye bars, pins, annealed	90–105,000	52,000	20	20	35
Steel splice bars:					
Low-carbon	55– 65,000	.....	25		
Medium carbon	68,000	.....	.....	1,600,000 Tens. str.	
High-carbon	85,000	.....	.....	14	
Extra-high carbon	100,000	.....	.....	10	
Quenched high carbon	100,000	65,000	.....	10	
Axles:					
Cold rolled steel	70,000	60,000 (El. Lim.)	.....	18	35
Tires—driving:					
Passenger engines	105,000	.....	.....	12	16
Freight engines	115,000	.....	.....	10	14
Switching engines	125,000	.....	.....	8	12
Steel forgings: See Serial, A 18–21, Standards, 1924.					

Metal	Tensile strength lb. per square inch		Minimum elongation per cent.		Contraction of area per cent.
	Ultimate	Yield point	in 8 in.	in 2 in.	
Steel castings:					
Hard castings	80,000	0.45 ultimate	.....	17	25
Medium castings	70,000			20	30
Soft castings	60,000			24	35
Concrete reinforcement bars, billet steel:					
Plain, structural grade	55–70,000	33,000	1,400,000 ultimate		
Plain intermediate grade	70–85,000	40,000	1,300,000 Tens. str.		
Plain, hard grade	80,000 min.	50,000	1,200,000 Tens. str.		
Deformed, structural grade	55–70,000	33,000	1,250,000 Tens. str.		
Deformed, intermediate grade	70–85,000	40,000	1,125,000 Tens. str.		
Deformed, hard grade	80,000 min.	50,000	1,000,000 Tens. str.		
Cold twisted	Recorded only	55,000	5		
Concrete reinforcement bars, rail steel:					
Plain bars	80,000	50,000	1,200,000 Tens. str.		
Deformed and hot twisted	80,000	50,000	1,000,000 Tens. str.		
Wrought iron:					
Staybolt iron	48–52,000	0.6 ultimate	30		48
Engine bolt iron	49–53,000	0.6 ultimate	25		40
Refined wrought iron	48–54,000	0.601+	25		
Forgings for locomotives and cars	45,000	0.5 ultimate	.....	22 in. 4 in.	30
Gray cast iron:					
Light castings	18,000				
Medium castings	21,000				
Heavy castings	24,000				
Malleable cast iron	50,000	.....	.....	10	

NOTE.—When not otherwise stated values are the minimum allowed.

METHODS FOR METALLOGRAPHIC TESTS OF METALS[1]

Microscopic Examination

For unhardened iron and steel, the following process has given satisfaction:

1. After polishing, examine under a magnification of 50 to 150 diameters. Look for slag or cinder in wrought iron, manganese sulphide, etc., in steel, and size and shape of graphite in cast iron.

2. Etch with a saturated solution of picric acid in alcohol for 15 seconds. This reveals the pearlite by turning it darker than the accompanying ferrite or cementite. In wrought iron, any pearlite present shows up, and the general appearance will sometimes show whether the material was puddled, etc., or made from reheated scrap. Those who wish to bring out the ferrite grains can do so easily and quickly by etching with nitric acid. To this end, nitric acid of 1.42 specific gravity should be diluted with either:

(*a*) 90 parts by volume of water to 10 of acid,

(*b*) 75 parts by volume of water to 25 of acid, or preferably

(*c*) 96 parts by volume of amyl alcohol to 4 of acid.

3. Near the eutectoid point, that is, 0.6 to 1.0 per cent. of carbons it is often difficult to distinguish between thin envelopes of ferrite and cementite. This difficulty can be overcome by etching with a solution of sodium picrate, which turns cementite dark brown or black but does not color the other constituents. The solution is made by adding 2 parts of picric acid to 98 parts of a solution containing 25 per cent. of caustic soda and is used at 100°C.

4. In order to interpret the results of such an etching, they should be compared with standard etched specimens.

5. In the case of hardened and tempered steel the indications are less decisive than in the case of unhardened steel, probably because the former class has been studied less than the latter. Coarse grain, segregation of constituents, presence of oxide, etc., are all signs of bad material. For etching use a solution of 4 parts of nitric acid, specific gravity 1.42, in 96 of amyl alcohol. The time needed has to be found by trial in each case. Hence etch for 5 seconds, examine, re-etch if necessary, etc.

[1] For more complete methods see Year Book A.S.T.M., 1924 E-3-24.

6. Macroscopic examination shows up defects due to segregation blowholes, piping, and the like, and when used in connection with microscopic examination yields valuable information. A section is cut with a saw, filed smooth, and polished with No. 0 and No. 00 emery paper; it is then ready for etching.

Quite a number of etching reagents have been used to develop the structure. Whichever solution is chosen, the specimen is first carefully washed with a strong caustic potash solution, well rinsed under the tap, and then immersed in the etching solution. The following may be mentioned:

(*a*) Freshly prepared solution of 20 g. of I and 30 g. of KI, in 100 g. of water.

(*b*) Dilute HCl or H_2SO_4 up to 30 per cent. acid, using the 1.2 and 1.84 specific gravity respectively.

(*c*) Nitric acid, from 10 to 30 per cent. of the 1.42 specific gravity acid in 90 to 70 per cent. of water.

(*d*) Concentrated HCl, specific gravity 1.2.

(*e*) A solution of 10 or 12 parts of double copper-ammonium chloride in 90 or 88 parts of water.

To bring out the structure of wrought iron rapidly, (*d*) is used, while (*c*) or (*b*) will bring it out more slowly.

For steel, first etch with (*a*), which shows up the segregation of carbon very well. Take care not to over-etch; 5 seconds is enough for some materials. To show up the impurities and the segregation of MnS, slag, etc., (*d*) acts quickly, but (*b*) gives better results though taking longer.

Some prefer light etching, say after 1 or 2 minutes, but an older method is to etch with (*b*) very deeply, indeed to a depth so great that several hours may be needed to reach it. In this way the segregation of the carbon and the impurities like slag and MnS are shown simultaneously. A picture of the object thus etched can be had by treating it like an engraving, that is, inking it with printer's ink, and printing on white paper directly from it. A common letter-copying press is convenient for this printing.

STANDARD SPECIFICATIONS FOR PORTLAND CEMENT[1]

SERIAL DESIGNATION: C 9–21

1. **Definition.**—Portland cement is the product obained by finely pulverizing clinker produced by calcining to incipient fusion

[1] Authorized Reprint from the Copyrighted A.S.T.M. Standards 1924), American Society for Testing Materials, Philadelphia, Pa.

an intimate and properly proportioned mixture of argillaceous and calcareous materials, with no additions subsequent to calcination excepting water and calcined or uncalcined gypsum.

I. CHEMICAL PROPERTIES

2. **Chemical Limits.**—The following limits shall not be exceeded:

Loss of ignition, per cent	4.00
Insoluble residue, per cent	0.85
Sulfuric anhydride (SO_3), per cent	2.00
Magnesia (MgO), per cent	5.00

II. PHYSICAL PROPERTIES

3. **Specific Gravity.**[1]—The specific gravity of cement shall be not less than 3.10 (3.07 for white Portland cement). Should the test of cement as received fall below this requirement a second test may be made upon an ignited sample. The specific gravity test will not be made unless specifically ordered.

4. **Fineness.**—The residue on a standard No. 200 sieve shall not exceed 22 per cent. by weight.

5. **Soundness.**—A pat of neat cement shall remain firm and hard, and show no signs of distortion, cracking, checking, or disintegration in the steam test for soundness.

6. **Time of Setting.**—The cement shall not develop initial set in less than 45 minutes when the Vicat needle is used or 60 minutes when the Gillmore needle is used. Final set shall be attained within 10 hours.

7. **Tensile Strength.**—The average tensile strength in pounds per square inch of not less than three standard mortar briquettes (see Section 50) composed of one part cement and three parts standard sand, by weight, shall be equal to or higher than the following:

Age at test,[2] days	Storage of briquettes	Tensile strength, lb. per sq. in.
7	1 day in moist air, 6 days in water	200
28	1 day in moist air, 27 days in water	300

[1] A.S.T.M. Standard Specifications for Portland Cement, Serial Designation C-9–26 lists no specific gravity requirement.

[2] A.S.T.M. Standard Specifications for Portland Cement, Serial Designation C-9–26 requires a 7-day strength of 225 lb. per sq. in. in tension and a 28-day strength of 325 lb. per sq. in. in tension for standard mortar briquettes.

8. The average tensile strength of standard mortar at 28 days shall be higher than the strength at 7 days.

III. PACKAGES, MARKING AND STORAGE

9. **Packages and Marking.**—The cement shall be delivered in suitable bags or barrles with the brand and name of the manufacturer plainly marked thereon, unless shipped in bulk. A bag shall contain 94 lb. net. A barrel shall contain 376 lb. net.

10. **Storage.**—The cement shall be stored in such a manner as to permit easy excess for proper inspection and identification of each shipment, and in a suitable weather-tight building which will protect the cement from dampness.

IV. INSPECTION

11. **Inspection.**—Every facility shall be provided the purchaser for careful sampling and inspection at either the mill or at the site of the work, as may be specified by the purchaser. At least 10[1] days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 31 days shall be allowed for the completion of the 28-day test. The cement shall be tested in accordance with the methods hereinafter prescribed. The 28-day test shall be waived only when specifically so ordered.

V. REJECTION

12. **Rejection.**—The cement may be rejected if it fails to meet any of the requirements of these specifications.

13. Cement shall not be rejected on account of failure to meet the fineness requirement if upon retest after drying at 100°C. for one hour it meets this requirement.

14. Cement failing to meet the test for soundness in steam may be accepted if it passes a retest using a new sample at any time within 28 days thereafter.

15. Packages varying more than 5 per cent. from the specified weight may be rejected; and if the average weight of packages in any shipment, as shown by weighing 50 packages taken at random, is less than that specified, the entire shipment may be rejected.

[1] A.S.T.M. Standard Specifications for Portland Cement, Serial Designation C-9–26. [At least 12 days from the time of sampling shall be allowed for the completion of the 7-day test, and at least 33 days shall be allowed for the completion of the 28-day test.]

TENTATIVE SPECIFICATIONS AND TESTS FOR COMPRESSIVE STRENGTH OF PORTLAND-CEMENT MORTARS

AMERICAN SOCIETY FOR TESTING MATERIALS

Serial Designation: C 9-16T

These specifications and tests are issued under the fixed designation C 9; the final number indicates the year of original issue, or in the case of revision, the year of last revision.

ISSUED, 1916

SPECIFICATIONS

1. **Compressive Strength.**—The average compressive strength in pounds per square inch of not less than three standard mortar test pieces (see Section 4) composed of one part cement and three parts standard sand, by weight, shall be equal to or higher than the following:

Age at test, days	Storage of test pieces	Compressive strength, lb. per sq. in.
7	1 day in moist air, 6 days in water	1200
28	1 day in moist air, 27 days in water	2000

2. The average compressive strength of standard mortar at 28 days shall be higher than the strength at 7 days.

3. The requirements governing the preparation of standard sand mortars for tension test pieces shall apply to compression test pieces.

SPECIFICATIONS FOR AGGREGATES

(1) American Railway Engineering Association, 1920, for Structures

Fine Aggregate.—The fine aggregate shall consist of sand, crushed stone or gravel screenings, graded from fine to coarse, and passing when dry, a screen having holes one-quarter (¼) inch in

diameter. Not more than 25 per cent. by weight shall pass a No. 50 sieve, and not more than 6 per cent. a No. 100 sieve when screened dry, nor more than 10 per cent. dry weight shall pass a No. 100 sieve when washed on the sieve with a stream of water. It shall be clean and free from soft particles, mica, lumps of clay, loam or organic matter.

Coarse Aggregate.—The coarse aggregate shall consist of gravel or crushed stone, which, unless otherwise specified or called for on the plans, shall, for plain mass concrete, pass a screen having holes two and one-quarter (2¼) inches in diameter, and for reinforced concrete a screen having holes one and one-quarter (1¼) inches in diameter; and be retained on a screen having holes one-fourth (¼) inch diameter, and shall be graded in size from the smallest to the largest particles. It shall be clean, hard, durable and free from all deleterious matter; coarse aggregate containing dust, soft or elongated particles shall not be used.

(2) Indiana State Highway Commission for Concrete Roads

Fine Aggregate.—The fine aggregate shall consist of sand composed of clean, hard, durable grains. When tested dry by means of laboratory screens and sieves, it shall meet the following requirements.

Retained on ¼ inch screen, not more than.....	5 per cent.
Retained on No. 8 sieve, not more than.....	25 per cent.
Retained on No. 28 sieve.....50 to	80 per cent.
Retained on No. 100 sieve, not less than.....	95 per cent.

It shall be free from organic matter and not more than two (2) per cent., by weight, shall be removed by the elutriation test.

(*a*) Strength Test.—Mortar composed of one (1) part Portland cement and three (3) parts fine aggregate, by weight, when mixed in accordance with the method described in Cir. No. 33, U. S. Bureau of Standards, shall have a tensile strength at the age of seven (7) and twenty-eight (28) days of not less than one hundred (100) per cent. of that developed by mortar of the same proportions and consistency, made of the same cement and standard Ottawa sand.

Coarse Aggregate.—The coarse aggregate shall consist of gravel or crushed stone conforming to the specifications herewith.

When a central proportioning or mixing plant is used, coarse aggregate may be delivered to the work in two or more gradations of sizing. These different grades shall be kept separated at all

times until used and shall then be combined under the supervision and direction of the Engineer and in such proportions as specified by him.

(*a*) Crushed Stone.—Crushed stone shall be obtained from clean, tough, durable rock having a French coefficient of wear of not less than seven (7). It shall be free from vegetable or other objectionable matter, and reasonably free from thin and elongated stone.

When tested by means of laboratory screens and sieves it shall meet the following requirements:

Retained on 2½ inch screen	0 per cent.
Retained on 1 inch screen	25 to 60 per cent.
Retained on ¼ inch screen, not less than	90 per cent.
Retained on 8 mesh sieve, not less than	97 per cent.

(*b*) Gravel.—Gravel shall consist of clean, sound, hard stone, reasonably free from thin or elongated pieces, and containing not more than five (5) per cent. of soft pieces. Gravel containing clay or coating of any character shall not be used. When tested in accordance with the method described in Bulletin 949, U. S. Department of Agriculture, p. 3, its per cent. of wear shall not be more than fifteen (15). Pit run gravel shall not be used.

When tested by means of laboratory screens and sieves it shall meet the following requirements:

Retained on 2½ inch screen	0 per cent.
Retained on ¾ inch screen	20 to 65 per cent.
Retained on ¼ inch screen, not less than	85 per cent.
Retained on 8 mesh sieve, not less than	95 per cent.

Water.—Water used for this work shall be reasonably clean and free from oil, acid, alkali or vegetable substances.

Proposed Tentative Specifications for Commercial Sizes of Gravel, Broken Stone and Broken Slag, Amer. Soc. for Testing Materials—1920. D-24-20T

1. These specifications cover the standard size designations and maximum permissible range in mechanical analyses for nine commercial grades of broken stone and broken slag, when used in the construction of plain or bituminous macadam, bituminous concrete, sheet asphalt and cement-concrete roads and pavements.

Gravel:

MAXIMUM PERMISSIBLE RANGE IN MECHANICAL ANALYSIS FOR EACH SIZE

Percentage by Weight Passing Each Screen

Designated size, in.	Diameter of screen openings, in.							
	¼	½	¾	1	1½	2	2½	3½
0 – ¼*a*	95–100							
0 – ¼*b*	85–100							
¼– ½	*c*	95–100						
¼– ¾	*c*	.....	95–100					
¼–1	*c*	25– 75	.....	95–100				
¼–1½	*c*	.....	25– 75	.....	95–100			
¼–2	*c*	.....	.....	25– 75	.....	95–100		
¼–2½	*c*	.....	.....	.....	25– 75	.....	95–100	
1 –2	.....	.....	.....	0– 15	.....	85–100		
2 –3½	.....	.....	.....	.....	.....	0– 15	.....	85–100

a Additional requirements for grading shall be as follows:

Passing 20-mesh sieve..... 25 to 75 per cent.
Passing 50-mesh sieve..... not over 25 per cent.
Passing 100-mesh sieve..... not over 5 per cent.

b Limits for silt and clay content may be inserted if desired.

Any percentage from 0 to 10 per cent. may be designated, with a maximum permissible variation therefrom of not more than 2½ per cent.

Broken Stone and Broken Slag.—The designated size or each grade together with the corresponding maximum permissible variations in mechanical analyses as determined by the use of laboratory screens, are given in the following table: (D-63-20T)

Maximum Permissible Range in Mechanical Analysis for Each Size

Percentage by Weight Passing Laboratory Screens

Designated size, in.	Diameter of screen openings, in.						
	¼	½	¾	1	1¼	2½	3½
0 – ¼	85–100						
0 – ½	0– 75	95–100					
0 – ¾	40– 80	.....	95–100				
¼– ¾	0– 15	25– 75	95–100				
¼–1¼	3– 10	.....	65– 85	.....	95–100		
¼–2½	0– 5	.....	.....	.....	25– 75	95–100	
¾–1¼	.....	.....	0– 15	25– 75	95–100		
1¼–2½	.....	.....	.....	.....	0– 15	95–100	
2½–3½ *a*	.....	.....	.....	.....	.....	0– 15	95–100

a In the case of light or porous slags a 4-in. maximum size may be specified instead of 3½ in.

APPENDIX III

Standard Forms of Test Pieces

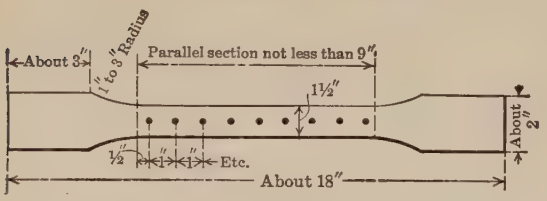


Fig. 1.—Wrought iron, structural steel and boiler plate. Plate metal in general.

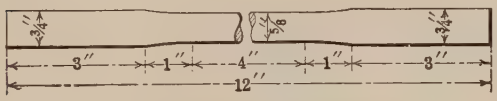
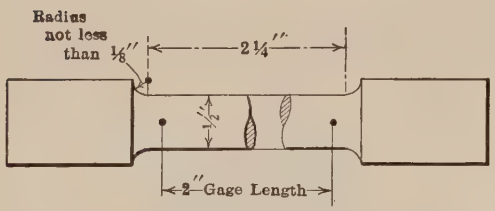


Fig. 2.—Malleable cast iron.



Note:- The Gage Length, Parallel Portions and Fillets shall be as Shown, but the Ends may be of any Form which will Fit the Holders of the Testing Machine.

Fig. 3.—Structural steel, wrought iron, steel castings and forgings, axle and tire steel.

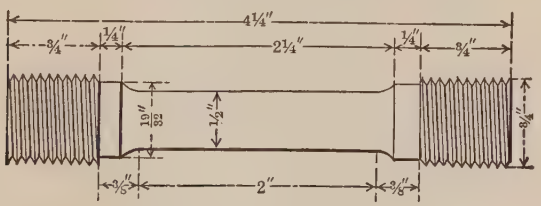
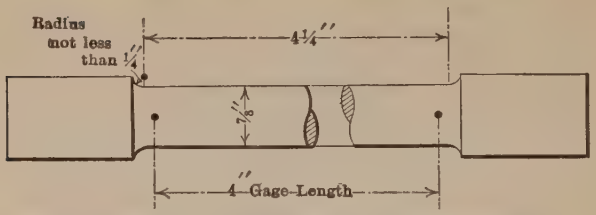


Fig. 4.—Screw end test piece.



Note:- The Gage Length, Parallel Portions and Fillets shall be as Shown, but the Ends may be of any Form which will Fit the Holders of the Testing Machine.

FIG. 5.—Wrought iron forging for locomotives and cars.

Mold for Gray Cast Iron Test Specimens.—The form and dimensions of the mold for the arbitration test bar shall be in accordance with Fig. 1. The bottom of the bar shall be $\frac{1}{16}$ in. smaller in diameter than the top, to allow for draft and for the strain of pouring. The pattern shall not be rapped before withdrawing. The flash shall be rammed up with green molding sand, a little damper than usual, well mixed and put through a No. 8 sieve, with a mixture

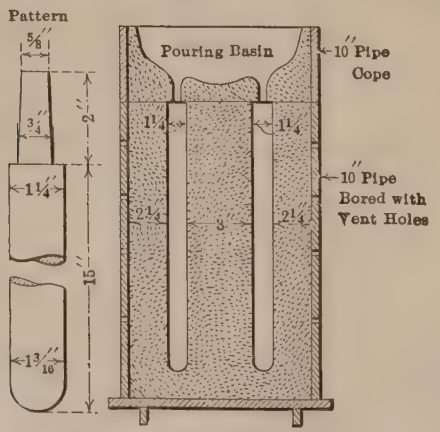


FIG. 6.—Mold for arbitration test bar.

of 1 to 12 bituminous facing. The mold shall be rammed evenly and fairly hard, thoroughly dried, and not cast until it is cold. The test bar shall not be removed from the mold until cold enough

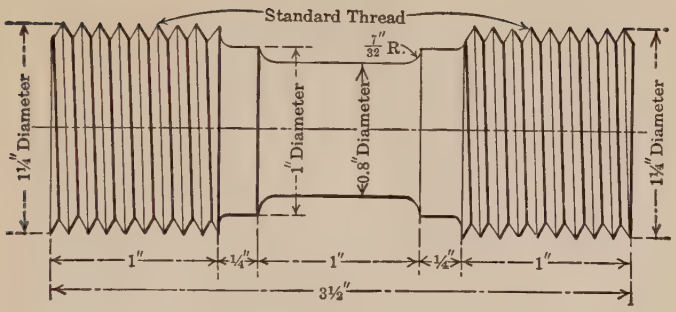


FIG. 7.—Arbitration test bar. Tensile test piece.

to be handled. It shall not be rumbled or otherwise treated, being simply brushed off before testing.

TABLE 1.—MECHANICAL PROPERTIES OF IRON AND STEEL. VALUES ARE RANGE OF AVERAGE, EXCLUDING HIGH AND LOW INDIVIDUAL RESULTS

Material	Spec. grav.	Tension—(1000 lb. per sq. in.)					Compression at failure	Shear, ultimate strength	Bending, mod. of rupture
		Ultimate strength	Elastic ratio		Ultimate elongation	Mod. of elasticity			
		Sm	at elastic limit	at yield point	Eu	E	Sc	Ss	Sr
Cast iron (gray iron)	7.207	15– 24	0.33	....	0.1–1.0 (in 2″)	12–14,000	Sc = 6Sm	Ss = 1.1Sm	Sr = 2Sm
Malleable cast iron	.....	38– 46	....	0.60	6–10 (in 4″)	.....	Sc = 4Sm	.....	Sr = 2Sm
Wrought iron	7.78	42– 52	Ratio of Sp to Sm = 0.5	0.66	22–30 (in 8″)	26–29,000	Sc = Sy	Ss = .85Sm	Sr = Sm
Steel:									
Extra soft	.....	45– 55		0.66	27–33 (in 8″)	Modulus of elasticity of all steels varies from 28–31,000,000. Average = 30,000,000 lb. sq. in.	Sc = Sy (When short cylinder is tested on artificial ultimate strength > Sy may appear	Ss = 0.75 Sm for hard + soft steels (Arnold)	Sr = Sy
Soft (C. 0.08–0.15)	7.833	50– 60		....	25–30 (in 8″)				
Medium (0.15–0.30)	.....	60– 70		0.63	22–25 (in 8″)				
Hard (C. 0.3 up)	.....	70– 80		0.55	22–18 (in 8″)				
Rails (0.64–0.55)	.....	101–102		0.50	12–15 (in 2″)				
Steel castings	7.917								
Soft	.....	60– 72		0.66	22–up (in 2″)				
Medium	.....	72– 78		....	16–22 (in 2″)				Sr = Sy
Hard	.....	78–up		....	12–16 (in 2″)				
Steel forgings	.....	75– 90		....	22–24 (in 2″)				
Spring steel:									
Untempered	.....	101–135			2.8–6.5 (in 8″)				
Tempered		130–200	0.85	....	2.1–0.5 (in 8″)				
Nickel steel:									
Structural	.....	100–120	0.50	0.58	16–20 (in 8″)				
Forging (annealed)	.....	80	....	....	30 (in 2″)				
Forging (oil-tempered)	.....	98	....	....	25 (in 2″)				
Vanadium steel:									
(*a*) Annealed	.....	54– 96	....	....	22–44 (in 2″)				
(*b*) Oil-tempered	.....	125–232	....	....	11–21 (in 2″)				

TABLE Ia.—MECHANICAL PROPERTIES OF COPPER AND ALLOYS

STRENGTH—in 1000 lb. per sq. in. units

Metals	Spec. grav.	Tens. strength		Mod. of elasticity	Comp. strength	Bending mod. of rupture	Shear
		El. limit	Ultimate				
Copper, cast	8.87	11–15	22–28	10–15	39–48	20–40	22–28
Copper, wrought	8.90	.....	29–36	12.5–16.8	58.000	30–60	
Brass, cast	8.00	.....	22.4–26.9	8.6–10	13.7 el. lim.	....	22.4–26.9
Aluminum, cast	2.57	4–6.5	11–16.5	8–11	12	2.34	12–16
Aluminum, rolled	2.72	12.5–14	16.5–22.4	9.7–10	18.8 el. lim.		
Duralumin (quenched and aged)	3.00	....	58				
Zinc, cast	7.1	4–9	2.2–6.75	12–14	22	7.5	
Zinc, wrought	7.2	.....	15.7–22.4				
Tin	7.28	2.0	4–5	3–6	6.4	4.15	
Gun metal	8.6	.....	25–50	10	.....	.....	33.6
Phosphor bronze	8.7	20.0	36–40.5	12–14	.....	.....	14.5
Manganese bronze	.....	30	65–85				
Tobin bronze	.....	51–56	66–80	4.5			
Aluminum bronze (90 per cent. Cu, 10 per cent. Al)	7.7	.....	100	16.8	.....	.....	56

TABLE Ib.—STRUCTURAL TIMBER

STRENGTH—expressed in 100 lb. per sq. in.

Kind of timber	Bending		Shearing		Compression	
	Extreme fib. stress	Modulus of elasticity	Parallel to grain	Longitudinal shr. in beams	Perpendic. to grain	Parallel to grain
	Average ultimate	Average	Average ultimate	Average ultimate	Elastic limit	Average ultimate
Douglas fir	61	15,100	6.9	2.7	6.3	36
Longleaf pine	65	16,100	7.2	3.0	5.2	38
Loblolly and shortleaf pine	56	14,800	7.1	3.3	3.4	34
White pine	44	11,300	4.0	1.8	2.9	30
Spruce	48	13,100	6.0	1.7	3.7	32
Norway pine	42	11,900	5.9	2.5	...	26
Tamarack	46	12,200	6.7	2.6	...	32
Western hemlock	58	14,800	6.3	2.7	4.4	35
Redwood	50	8,000	3.0	...	4.0	33
Bald cypress	48	11,500	5.0	...	3.4	39
Red cedar	42	8,600	...	...	4.7	28
White oak	57	11,500	8.4	2.7	9.2	35

TABLE Ic.—STONE AND BRICK

ULTIMATE STRENGTH—in units of 1000 lb. per sq. in. (subject to variation of 50 per cent. of average each way)

Material	Spec. grav.	Comp. Sc	Tens. Sa	Flex. Sr	Shear Sr	Mod. of elast E (1)	Absorption	
			In per cent. of Sc					
Granite	2.67	19.4	←About 4 %→	8.5	Varies with method of test from 10 to 20 %	4600	1/750	
Limestone	2.53	9.5		18.0		4700	1/38	
Limestone oolitic	2.48	6.7		18.0		4700	1/23	(1) at working stresses
Marble	2.72	12.7		15.0		7000	1/300	(2) Bauschinger. Poisson's ratio = ¼
Sandstone	2.22	9.3		14.0		2200	1/24	
Slate	2.77	14.0		15.0		....	1/435	
Trap	2.92	32.0(2)						
Brick (3)								
Common	....	4.0	}	15.0		1300	1/3	
Hard burned	....	12.0				4000	1/6	(3) Tests on ½ brick in plaster of Paris
Paving (best) (4)	....	7.5	.....	33.0	.....	....	1/100	
Sand lime	.....	3.5	.....	15.0	.....	....	1/10	(4) Rattler loss N. B. M. A. test = 18%
Brick masonry								
1 to 6 lime mortar	....	Sc = 0.14 Sc of brick on edge						
1 to 3 cement mortar	. .	Sc = 0.32 Sc of brick on edge						
1(15 % lime; 85% cement) to 3 sand		Sc = 0.30 Sc of brick on edge						

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